THE TEMPERATURE-PRESSURE DEPENDENCE OF IONIC CONDUCTIVITY IN SEA WATER AT TEMPERATURES IN THE OCEANIC RANGE

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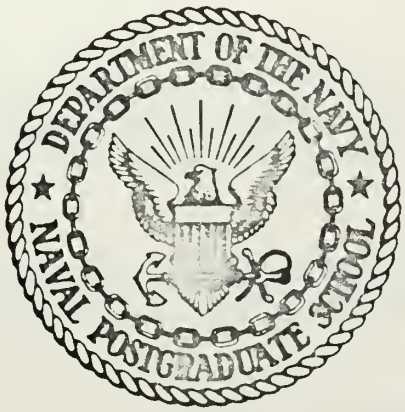

THESIS

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The Temperature-Pressure Dependence of Ionic Conductivity in Sea Water at Temperatures in the Oceanic Range

by

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Lieutenant, United States Navy
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ABSTRACT

The specific conductance of three sea water samples (33.634°/oo, 34.099°/oo and 35.001°/oo) was measured at twelve temperatures from 0°C to 21.00°C and at nine pressures from atmospheric to 4,141.8 decibars above atmospheric. Polynomials for specific conductance as a function of temperature and as a function of pressure are computed from the data, but the temperature-pressure effect is obscure.

Two empirical equations that relate conductivity ratio to temperature and pressure are also developed. These equations better describe the temperature-pressure effect on conductivity at the pressures studied which correspond to the upper 4,000 meters of the ocean.

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I. INTRODUCTION

In recent years, measurement of the electrical conductivity of sea water has become the most common method of determining the salinity of sea water. As a result, UNESCO has defined salinity in terms of a conductivity ratio (International Oceanographic Tables, 1966). Salinity has been so defined because there is good evidence that there is better correlation between the density and salinity calculated from conductivity than between the density and salinity calculated from chlorinity (Cox et al., 1962).

Conductivity ratio is the ratio of the conductivity of an electrolyte of unknown concentration to the conductivity of a known standard concentration of the electrolyte. In the case of sea water, the standard is Standard Sea Water with an exactly measured value near $35^{o}/oo$ (parts of dissolved salts per one thousand parts of sea water). The ratio is formed with both the sample and standard at the same temperature and at a pressure of one atmosphere. This ratio can be represented as : $K(S,T,O)/K(35,T,O)$ where the pressure variable is "sea pressure" so that zero denotes a pressure of one atmosphere.

Commonly, conductivity ratio of sea water is measured using a laboratory salinometer that is calibrated several times a day, using standard sea water, when in use. The measured ratio is then converted to a ratio at the temperature ($15^{o}C$) for which salinity is defined by UNESCO.

Conductivity ratio is also measured using an in situ salinometer which measures the ratio $K(S,T,P)/K(S,T,O)$ and converts this through instrumentation to a ratio $K(S,T,P)/K(35, 15, 0)$, which in turn is used to obtain salinity. The measurement of conductivity ratio in situ requires a knowledge of the effects of temperature and pressure on conductivity. The in situ salinometer has been a major development in the collection of oceanographic data and has been described by Hamon (1955), Prichard (1959) and Siedler (1963).

The effect of temperature and pressure on ionic conductivity has been studied previously. However, the temperature-conductivity relationship has usually been studied at atmospheric pressure, and the pressure-conductivity relationship at only a few temperatures.

With the increased use of in situ measurements in oceanography, this study was undertaken in an effort to investigate further the temperature-pressure relationship with conductivity.

II. PREVIOUS INVESTIGATIONS

Many studies on the conductivity of aqueous solutions have been made since the turn of the century, but only in the last thirty years has serious research using sea water been carried out. The majority of the investigations to date have concentrated on temperature effects, and only since the late 1950's have studies of pressure effects become prominent.

A. STUDIES MADE AT ATMOSPHERIC PRESSURE

Thomas, Thompson, and Utterback (1934) conducted one of the earliest and most extensive studies of the effect of temperature on the conductivity of sea water. They studied sea water that ranged in chlorinity from 1°/oo to 22°/oo at temperatures of 0°C, 5°C, 10°C, 20°C and 25°C. The results of this study remained for many years the best information available, and was adequate for salinity determinations using inductive or conductive salinometers where specific conductance of a sample is compared to a standard by forming a conductivity ratio.

Pollack (1954) criticized the work of Thomas et al. because of experimental errors from two sources: (1) Thomas et al. used the results of Parker and Parker (1924) for the specific conductances of standard KCl solutions to calibrate the conductivity cell. The Parker and Parker values are in error due to capacitive effects between parts of the cell that were of opposite polarity according to Jones and Bradshaw (1933). Jones and Bradshaw developed new values for specific conductance of standard KCl solutions. (2) the conductivity cells (Washburn pipet type) used by Thomas et al. allowed a capacitive shunt (similar to that of Parker and Parker) that could produce an error.

These two sources of error are opposite in sign and would tend to cancel each other, but to what extent is indeterminate.

Weyl (1964) reviewed the data of Thomas et al. and developed a polynomial for evaluating the change in specific conductance ($\frac{dK}{dt}$)

at atmospheric pressure as a function of chlorinity and temperature. Weyl also developed a polynomial for specific conductance (K) as a function of chlorinity and temperature.

Malmberg (1965) has studied the conductivity of very dilute solutions of sea water such as would result from a distillation process.

Reeburgh (1965) measured the specific conductance of Red Sea water that had been diluted to various chlorinities at several temperatures. Reeburgh's results are in fair agreement with those of Thomas et al. when expressed as error in "equivalent chlorinity."

Park (1964a) showed that dissolution of $CaCO_3$ in sea water may result in as much as 0.006°/oo change in salinity if conductivity measurements are used to estimate salinity. Park (1964b) also determined the partial equivalent conductances of 16 of the electrolytes in sea water.

B. STUDIES MADE AT ELEVATED PRESSURES

Adams and Hall (1931) conducted one of the earliest studies of the effect of pressure on conductivity. They made measurements on various concentrations of NaCl solutions and on a few other prepared solutions.

Hamon (1958), apparently, was the first to investigate the effect of pressure on sea water. The study occurred during his development of an in situ salinometer. Measurements were made on a single sample of artificial sea water at four different temperatures. Pressure was increased in three steps by using compressed nitrogen up to a pressure of about 900 decibars. Adiabatic compression was assumed and an

appropriate temperature correction applied after each pressure increase. Hamon described his results as only tentative with an estimated accuracy of the pressure coefficients of 5%. He concluded that the relationship between pressure and conductivity was linear.

Horne and Frysinger (1963) conducted an investigation of the properties of sea water at elevated pressures, including electrical conductivity. They measured the specific conductance of three samples of artificial sea water at 0°C, 5°C, 15°C and 25°C at pressures up to 13,800 decibars (approximately a depth of 13,800 meters) in increments of 1,380 decibars. Temperature was controlled by a constant temperature bath to $\pm$0.05°C. Horne and Frysinger found that conductivity as a function of pressure was linear up to 6,890 decibars and that the slope of the conductivity vs. pressure plot was independent of temperature in the range studied. They developed a linear equation that relates the specific conductance at any pressure, temperature and chlorinity to the specific conductance at atmospheric pressure, and at the same temperature and chlorinity.

Bradshaw and Schleicher (1965) made measurements of the fractional increase in electrical conductance on three different solutions of salinity: 31°/oo, 33°/oo and 39°/oo. Their measurements, at six temperatures and pressures up to 10,338 decibars, were the first to be made using natural sea water. The pressure was increased in steps of 1,723 decibars for each sample at each temperature. They estimated

that the measurements had a precision of better than 0.01°/oo in equivalent salinity change. Bradshaw and Schleicher developed an empirical relationship for the per cent increase in conductance that fit their data with a standard deviation of 0.002°/oo in equivalent salinity error. However, there is a significant residual error near atmospheric pressure.

Mays (1968) made the first study of the effect of pressure in which the pressure was increased in relatively small increments. Mays studied five solutions (two sea water) at four temperatures up to a pressure of 2,000 decibars. Measurements were made in a pressure vessel surrounded by a cooling coil, but no provision was made for measuring temperature of the water samples above atmospheric pressure. To allow for heat generated by the nearly adiabatic compression, Mays waited an arbitrary 15 minutes after each pressure increase before recording any data. Mays concluded that the specific conductance is related by a higher order relationship to pressure. Due to the lack of temperature measurements, the nonlinearities suggested by Mays may be due to temperature fluctuations.

Ettle (1969) investigated the effect of pressure on conductance of two natural sea water samples at six temperatures and pressures to 4,000 decibars. Ettle also estimated the effects that cause the increase in specific conductance of sea water at elevated pressures. He found that the change in specific conductance with pressure, while

nearly linear, must be described by a higher order polynomial. The standard deviation for second and third degree equations was 0.041°/oo equivalent error in salinity and fit the Bradshaw and Schleicher equation with a standard deviation of 0.066°/oo. Ettle thus confirmed that the higher order results of Bradshaw and Schleicher are more descriptive of the relationship between specific conductance and pressure. However, more investigation into the effect of pressure at the temperatures characteristic of the ocean water column is needed in order to improve the data obtained from in situ measurements of salinity.

III. EQUIPMENT

The equipment used in this study was the same as that used by Ettle (1969). However, the pressure vessel was remachined, the conductivity cell was rebuilt, another pressure gauge was used and an oscilloscope was utilized vice earphones as a bridge balance detector.

A. PRESSURE VESSEL

The pressure vessel was made in three major pieces: the base, the barrel and the piston (Figure 1). The interior, where the conductivity cell was located, of the vessel when assembled was about 1.5 inches in diameter and 7 inches deep.

The base had a 1.5 inch hole bored to a depth of one inch, to serve as a receptacle for the conductivity cell that extended below the level of the cell electrodes. There were three radial grooves cut into the

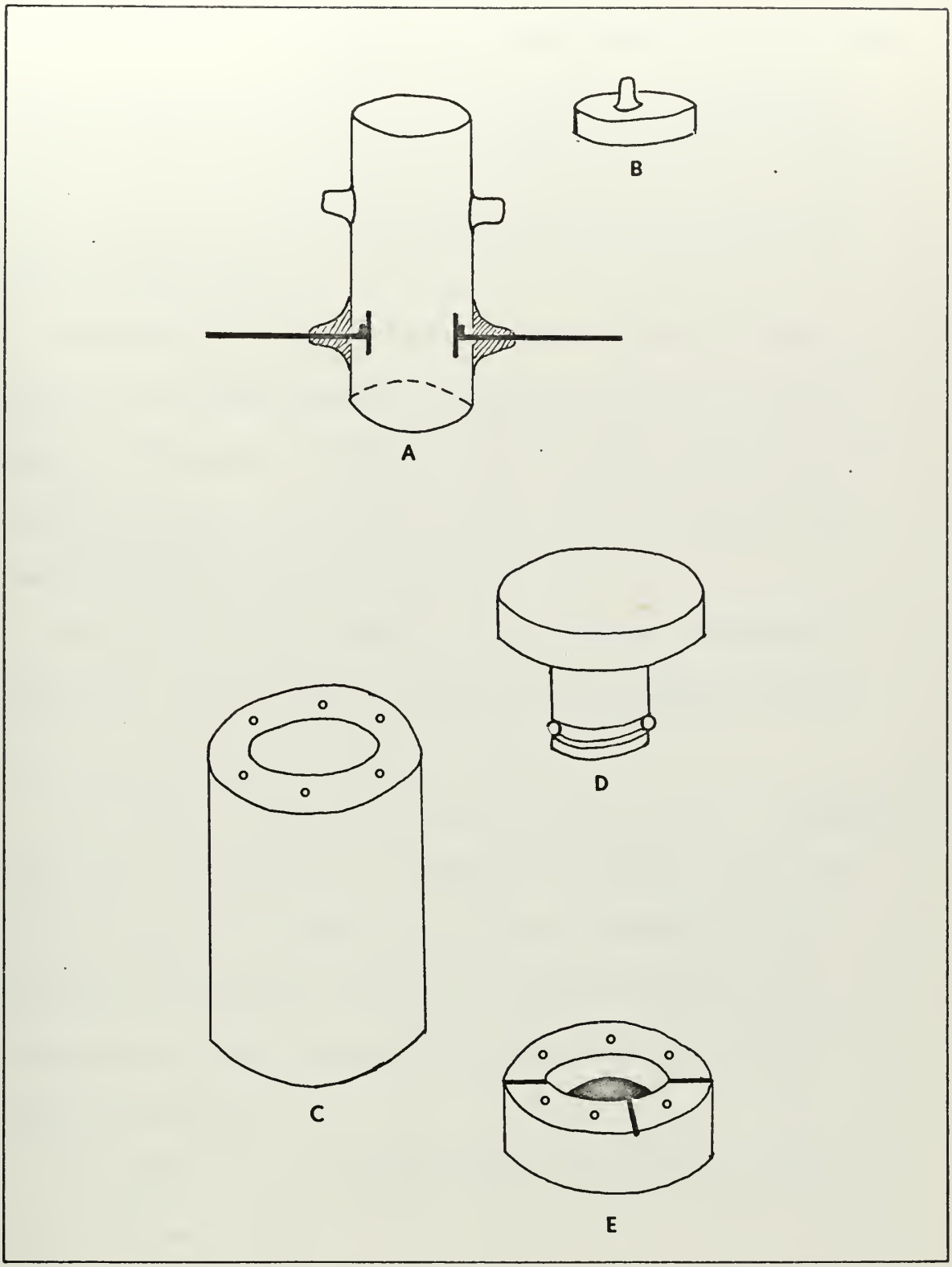

Figure 1. Schematic Drawing of the Conductivity Cell and Pressure Vessel. A--Conductivity Cell, B--Glass Cover, C--Pressure Vessel Barrel, D--Pressure Vessel Piston, E--Pressure Vessel Base.

top of the base two grooves which were diametrically opposite each other and provided for the cell external connecting leads. The third groove provided the location of the copper-constantan thermocouple. All leads were wrapped with TEFLON tape to provide electrical insulation and make a pressure seal.

The barrel of the vessel was about 6 inches high with a 1.5 inch bore and 5 inch outside diameter. A circular groove was cut into the bottom of the barrel to accept a neoprene 0-ring that made a pressure seal when the barrel was bolted to the base. The base and barrel were bolted together by six stainless steel bolts.

The piston was made slightly smaller in diameter than the bore of the barrel. A pressure seal was obtained by using a neoprene 0-ring in a groove located near the bottom of the piston.

After the vessel was assembled, short lengths of plastic "spaghetti" were placed over each lead that penetrated the pressure vessel, then two-inch lengths of stainless steel tubing were installed over the "spaghetti" and secured to the side of the pressure vessel. This arrangement provided mechancical strength and isolated the leads from the cooling coil.

The cooling coil, 0.5 inch copper tubing, was placed around the assembled base and barrel.

B. CONDUCTIVITY CELL

The conductivity cell was constructed from a glass cylinder closed

at one end and fitted with a glass cover at the other end (Figure 1). Two glass stand-offs were located near the top of the cell. These stand-offs held the cell in position inside the pressure vessel. Platinum foil electrodes approximately one square centimeter in area were located about one inch from the bottom of the glass cylinder and tack-welded to platinum wire leads that penetrated the cylinder wall. The wire leads provided the necessary external connections for measuring conductance. The platinum leads were fixed to the cylinder using PLIOBOND electrical sealant.

The foil electrodes were coated with platinum black using Braun Chemical Co. platinizing solution and a 3 volt battery. After being platinized, the cell was kept full of distilled water when not in use.

C. PRESSURE

The assembled pressure vessel with piston in place, was put in a hydraulic press and pressure applied to the base and top of the piston. Hydraulic pressure was measured using an eighteen inch Heise gauge (H3156) with a range to 6,000 psi. The pressure inside the vessel could then be computed since the measured hydraulic pressure is directly related--by a ratio dependent upon the area of the respective pistons--to the pressure inside the vessel.

D. TEMPERATURE

Temperature in the vessel was controlled by pumping an ethylene glycol-water mixture from a Formatemp (2075B) thermostatically

controlled bath through the cooling coil that surrounded the vessel. The bath could control temperature to within $\pm$ 0.02°C. The temperature inside the vessel was measured with a copper-constantan thermocouple located at the same level as the platinum foil electrodes. Potential was measured by a Leeds and Northrup precision millivolt potentiometer (8690).

E. CONDUCTIVITY

The resistivity--the inverse of conductivity--of the water samples in the cell was measured with a Wheatstone bridge. The internal decade resistors could be adjusted in one ohm steps. In order to obtain the accuracy required, three decade resistance boxes (adjustable in 0.1 ohm steps) were connected in parallel and connected to the bridge. Bridge balance was observed using a Heathkit oscilloscope (EUW-25).

F. EQUIPMENT ACCURACY AND PRECISION

Pressure could be measured to an accuracy of 5 psig and the piston arrangement increased the pressure in the vessel by a factor of about 1.5 thus the pressure inside the vessel was accurate to 7.5 psi. This corresponds to an accuracy of 5.2 decibars or an equivalent salinity error of $\pm$0.003°/oo.

Temperature could be controlled to $\pm$0.02°C and measured with an accuracy of $\pm$0.01°C. This accuracy in temperature corresponds to an equivalent salinity error of $\pm$0.02°/oo.

Resistance of the cell could be measured--using the external decade resistors--with an accuracy of 0.01 ohm. Since resistances measured were of order 25 ohms, and the cell constant was about 0.7, this accuracy in resistance is equivalent to an accuracy of ±0.00001 mho/cm in specific conductance or an equivalent salinity error of ±0.01°/oo.

Experimental accuracy and precision are summarized in the following table:

Variable	Accuracy	Precision	Equivalent Salinity Error (°/oo)
Pressure (decibars)	5.2	5.2	±0.003
Temperature (°C)	0.01	0.02	±0.02
Specific Conductance (mho/cm)	0.00001	0.00001	±0.01

Thus, the maximum total experimental error is not greater than ±0.033°/oo error in equivalent salinity, and the most probable error is ±0.016°/oo.

IV. EXPERIMENTAL PROCEDURE

The conductance cell was calibrated while installed in the pressure vessel at atmospheric pressure and 0°C with 0.1M standard KCl solution. Conductivity of three water samples--two natural sea water and

standard sea water--was then determined at twelve temperatures at pressure intervals of 500 psi to a maximum of 4,000 psi.

A. CELL CALIBRATION

To accurately measure, from first principles, the specific conductance of an electrolyte, such as sea water, requires a cell with electrodes of accurately determined area and spacing. However, an effective value of spacing/area can be determined by using standard solutions of known concentration and known specific conductance. This factor--spacing/area (L/A)--is different for each cell and is called the cell constant. A cell constant for any given conductivity cell can be determined by:

$$K_o C = K_T \tag{1}$$

Where:

K_o = observed conductivity of standard solution as measured by a conductivity bridge (mho)

C = L/A = cell constant (cm^{-1})

K_T = specific conductance of standard solution of known concentration at a given temperature from literature (mho/cm)

Once a cell constant has been determined, the specific conductance of an unknown electrolyte can then be calculated from:

$$K_s = K'_o C \tag{2}$$

Where: K_s = specific conductance of sample at a known temperature and atmospheric pressure (mho/cm)

K_o' = observed conductivity of sample as measured by a conductivity bridge (mho)

C = cell constant (cm^{-1})

In this study, since the platinum leads of the cell were held in place by the pressure vessel and the cell penetrations were flexible, no changes in the cell constant with pressure were expected. However, a new cell constant determination was necessary whenever the pressure vessel and cell were disassembled.

B. STANDARD SOLUTIONS

Two different standard solutions of 0.1M KCl were made using reagent grade KCl crystals using the values and procedures according to Kortum (1965). The KCl crystals were first dried by heating for several hours and allowed to cool in a desiccator before weighing. Duplicate measurements of conductivity were made on each solution. The values of the measurements were within 0.00002 mho/cm of each other and the value used in determining the cell constant was the average of these four measurements. The distilled water used in making the standard solutions was found to have a specific conductance of 0.00016 mho/cm and was corrected for when calculating the cell constant.

C. WATER SAMPLES

A large parcel of natural sea water was collected from the southern end of Monterey Bay. This sample was divided into two parts; the first was used as collected; the other was left exposed to the air and allowed to evaporate at room temperature until a higher salinity was obtained. The salinity of each sample was determined using a Hytech (622) inductive salinometer and the final salinities were 33.634°/oo and 34.099°/oo. The third sample used was several ampoules of standard sea water with a chlorinity of 19.3745°/oo.

For each water sample, measurements were taken at twelve temperatures from near 0°C to 21°C with most measurements below 10°C. Measurements were taken in 500 psi increments up to 4,000 psi.

D. MEASUREMENTS

For each water sample studied, both the conductivity cell and pressure vessel were filled. Before filling, the equipment was rinsed twice with distilled water and twice with the particular water sample to be used. No aliquot of a sample was ever reused.

After filling the sample chamber, the glass cover and piston were installed and the pressure vessel placed in the hydraulic press. Conductivity of the sample was then determined at pressure increments of 500 psi from atmospheric to 4,000 psi and from 4,000 psi back to atmospheric. The measurements at each pressure were then averaged since the readings at each pressure were within 0.02 ohm of each other.

The temperature bath was adjusted to give a desired temperature within the vessel, and after each pressure change the bridge was balanced and temperature measured alternately until three consistent readings were obtained (within 0.01 ohm resistance and 0.02°C); then pressure, temperature and bridge resistance were recorded. Since no specific temperature was required, no adjustment of the bath for adiabatic heating or cooling was necessary following each pressure change.

All measurements were made at a frequency of 2,000 Hz, and occasionally a value was checked at 1,000 Hz to insure observations were independent of frequency.

V. EXPERIMENTAL RESULTS AND ANALYSIS

Experimental measurements were made on three sea water samples at twelve temperatures. At each temperature, three sets of data for values of conductivity at nine pressures were obtained. The results are tabulated in Tables I through III of Appendix A.

A. CONVERSIONS

Before detailed analysis of the experimental data could be performed, several conversions and determinations were required. The raw data consisted of gauge pressures, sample resistances, and temperatures.

1. Pressure

The hydraulic pressure in psig was converted to equivalent pressure inside the vessel and expressed in decibars. This established

some perspective of pressure and depth in the water column since 1 decibar corresponds, approximately, to a depth of 1 meter.

The pressure inside the pressure vessel is related to the hydraulic pressure by a ratio of the diameters of the hydraulic and vessel pistons.

$$P_V = P_h \left(\frac{D_h}{D_v}\right)^2 \times F \qquad (3)$$

Where: P_V = pressure inside pressure vessel (decibars)

P_h = hydraulic pressure observed (psig)

D_h = diameter of hydraulic piston (inches)

D_v = diameter of pressure vessel piston (inches)

F = factor for converting psig to decibars =0.68947 (Wilson and Bradley, 1968)

2. Conductivity

The conductivity bridge measures the resistance of the solution across the electrodes, which can be converted to specific conductivity.

The resistance of the external decade boxes connected in parallel was calculated by:

$$R_e = \frac{R1 \times R_2 \times R_3}{(R_1 \times R_2) + (R_2 \times R_3) + (R_1 \times R_3)} \qquad (4)$$

Where: R_e = total resistance of external decade boxes (ohm)

R_1 = resistance of first decade box (ohm)

R_2 = resistance of second decade box (ohm)

R_3 = resistance of third decade box (ohm)

The total cell resistance was obtained by adding the resistance measured by the conductivity bridge, the total external resistance, and a calibration constant of 0.06 ohm.

$$R_t = R_b + R_e + R_c \tag{5}$$

Where: R_t = total cell resistance (ohm)

R_b = resistance measured by conductivity bridge (ohm)

R_e = total external resistance (ohm)

R_c = calibration constant (ohm)

The observed conductivity in mhos is the reciprocal of the total resistance (R_t):

$$K_o = \frac{1}{R_t} \tag{6}$$

This may then be substituted into the expression for the specific conductance of an unknown electrolyte, to obtain the specific conductance of an unknown electrolyte, to obtain the specific conductance from total resistance:

$$K_s = \frac{C}{R_t} \tag{7}$$

Where: κ_s = specific conductance of unknown sample (mho/cm)

C = cell constant (cm^{-1})

R_t = total measured resistance (ohm)

3. Temperature

The thermocouple was calibrated against a precision mercury thermometer and sufficient time was permitted for thermal equilibration. No conversions or corrections to temperature were required. Temperatures inside the vessel, as sensed by the thermocouple, were obtained graphically from a determined calibration curve of temperature vs. potential.

4. Salinity

When comparing results of this investigation with the results of previous studies, and it was necessary to convert salinity to chlorinity, the following was used:

$$S^{o}/oo = 1.80655Cl^{o}/oo \qquad (8)$$

The data for all three solutions at 4.39°C and 0.42°C is of questionable accuracy since this data was taken first and it was noted that the pressure vessel piston had a tendency to drag when pressure was released. Therefore, the values for specific conductance at these two temperatures may not be at the recorded pressure.

B. DATA ANALYSIS

Analysis of the experimental data was performed using the IBM 360 digital computer at the Naval Postgraduate School. The raw data was punched onto IBM cards for processing. The computer program used for the analysis can be found at the end of this paper.

1. Temperature

The coefficients of the least square polynomial up to third degree, for specific conductance as a function of temperature, were determined at each pressure and are shown in Tables IV through VI (Appendix A). This polynomial is of the form:

$$\kappa(S,T,P) = A_1 + A_2T + A_3T^2 + A_4T^3 \qquad (9)$$

Where: A_i = coefficient at each pressure

T = temperature in degrees centigrade

The second and third degree curves fit the data with a standard deviation of less than $0.03^{o}/oo$ equivalent salinity error in all cases. Representative plots of the second degree fit are shown in Figures 2, 3, and 4.

2. Pressure

The coefficients of the least square polynomial up to third degree, were also computed for specific conductance as a function of

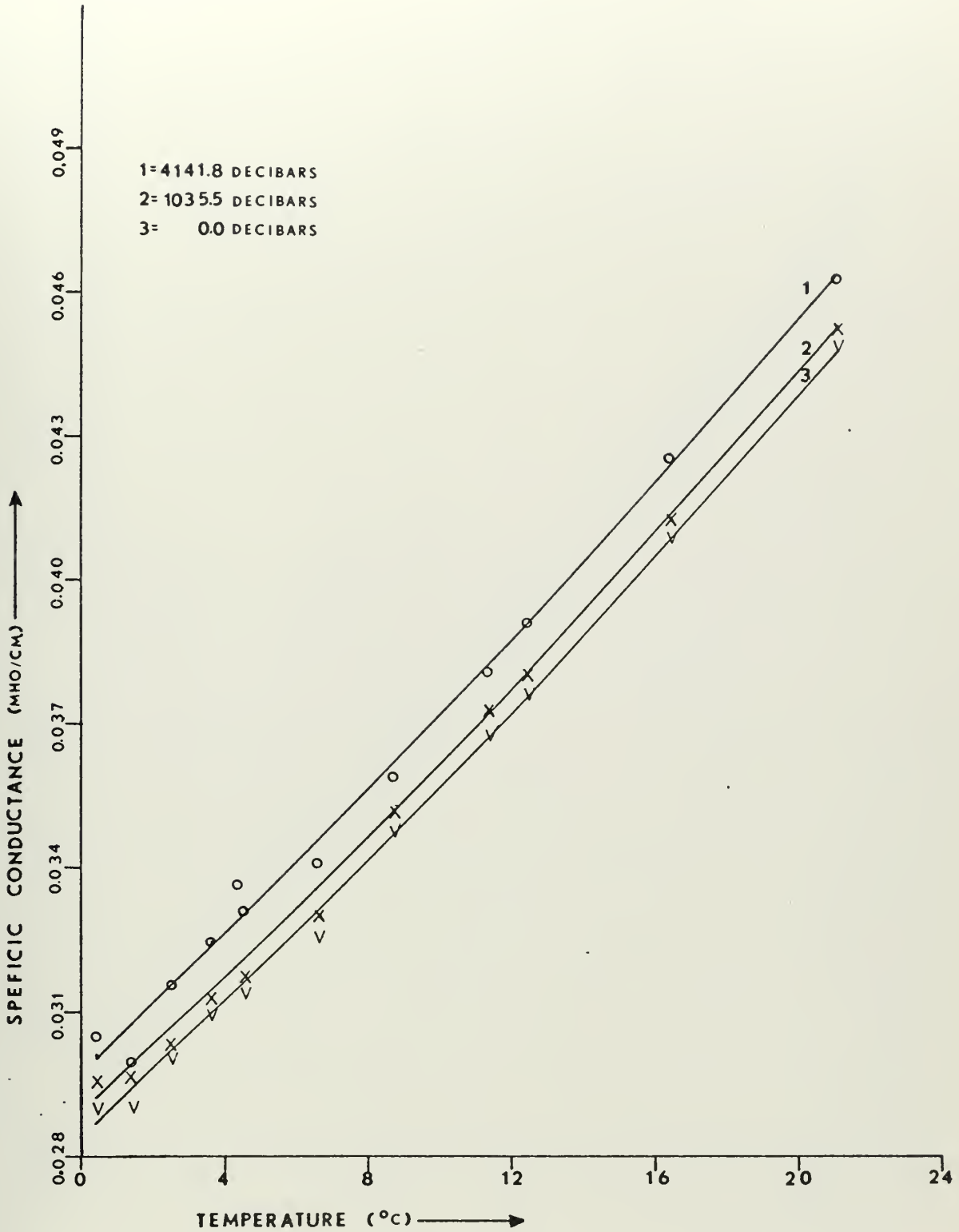

Figure 2. Specific Conductance vs. Temperature, Salinity=33.634°/oo, Second Degree Curve.

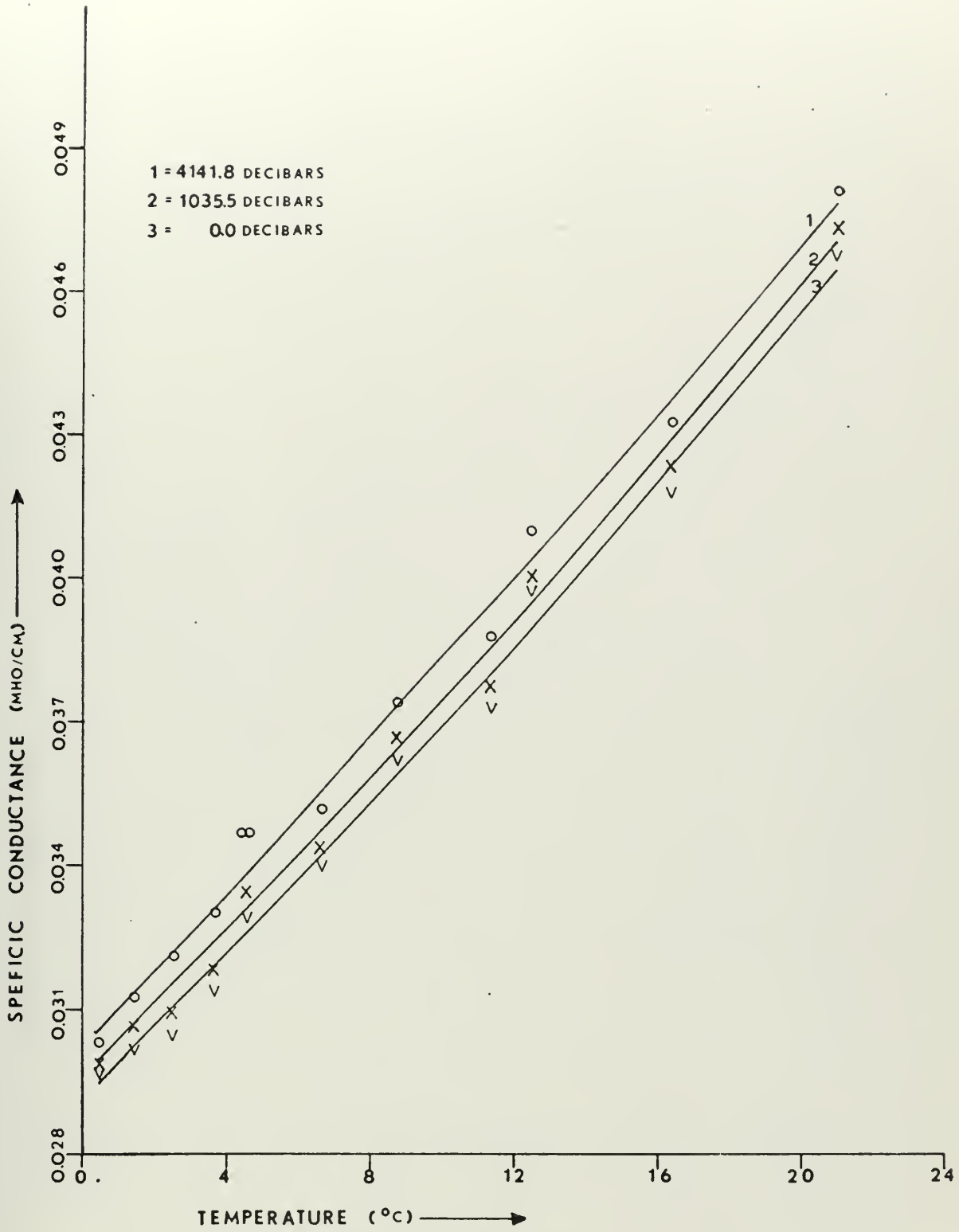

Figure 3. Specific Conductance vs. Temperature, Salinity=35.001°/oo, Second Degree Curve.

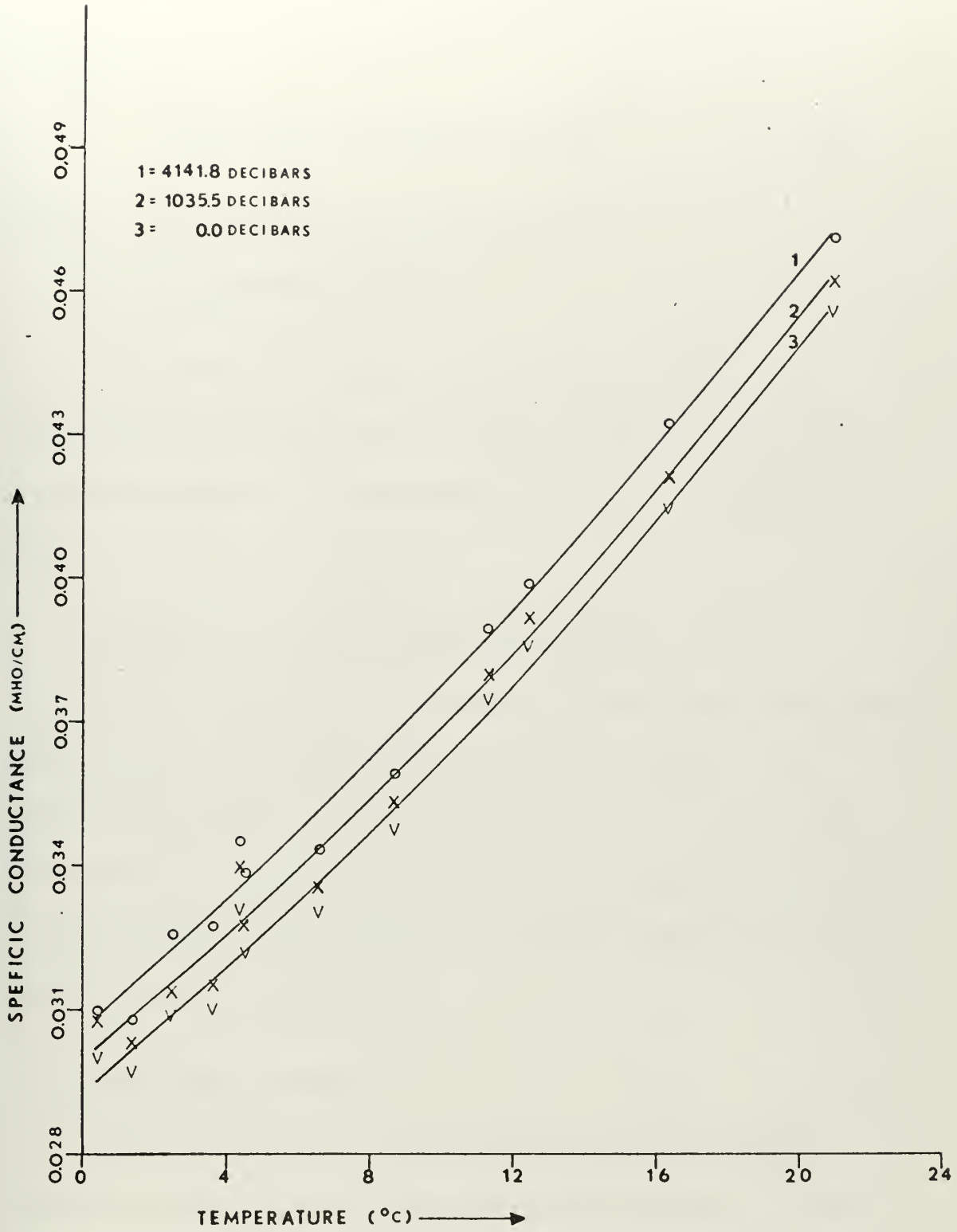

Figure 4. Specific Conductance vs. Temperature, Salinity=34.099°/oo, Second Degree Curve.

pressure and are shown in Tables VII through IX. This polynomial is of the form:

$$K(S,T,P) = B_1 + B_2P + B_3P^2 + B_4P^3 \qquad (10)$$

Where: B_i = coefficients at each temperature

P = pressure in decibars.

The second and third degree curves in this case fit the data with a standard deviation of less than 0.01°/oo equivalent salinity error. Representative plots of the second degree fit are shown in Figures 5, 6, and 7.

C. COMPARISON WITH PREVIOUS INVESTIGATIONS

The results of this study were compared with the values of electrical conductivity of sea water reported in previous investigations. The results were compared in a manner consistent with each previous study. For example, if the previous results were reported as a conductivity ratio, the data from this study was converted to a conductivity ratio before comparisons were made.

1. Atmospheric Pressure

The values of specific conductance observed at atmospheric pressure were found to be about 1% less than those reported by Thomas et al. (1934) or Reeburgh (1965). However, the observed values are in

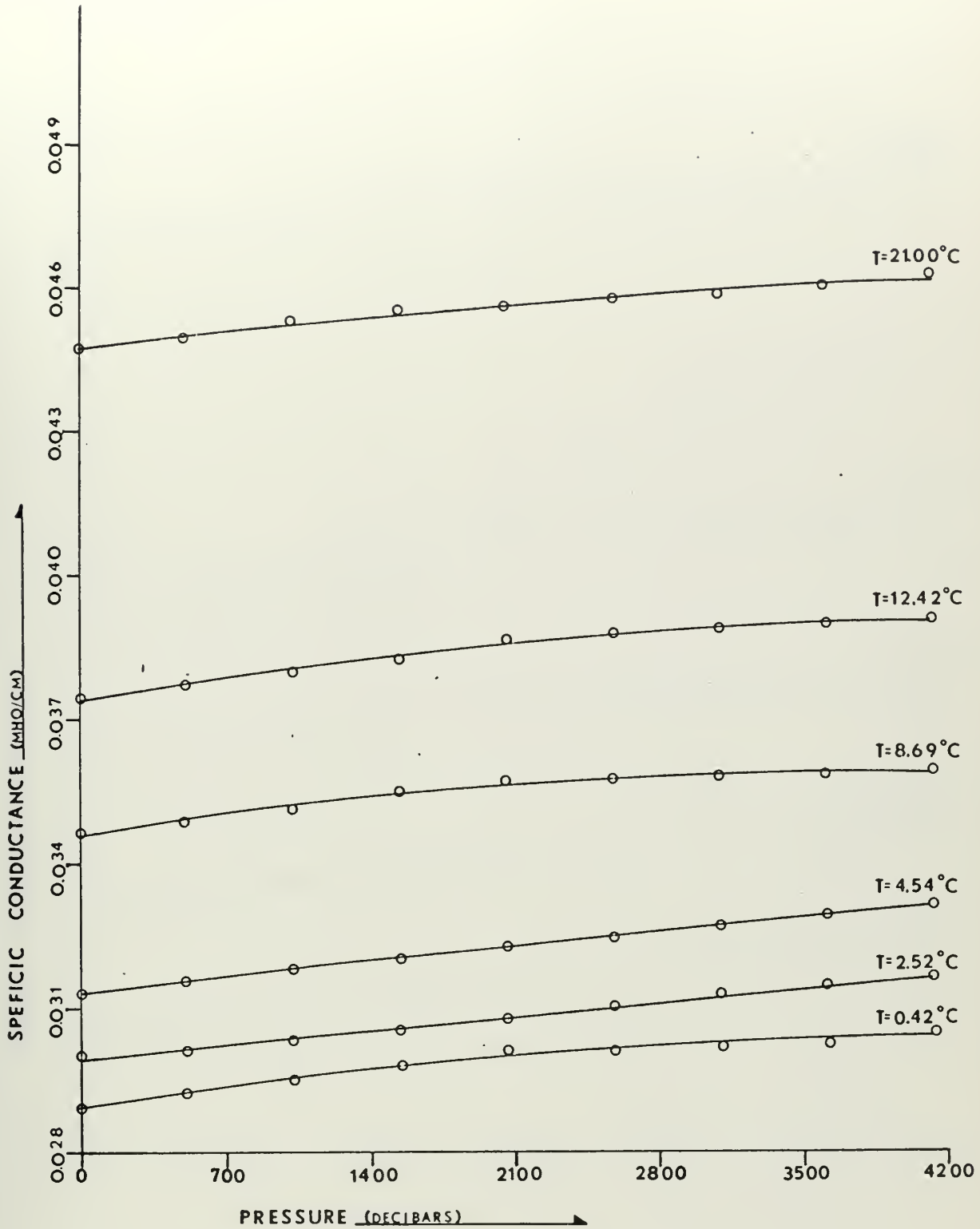

Figure 5. Specific Conductance vs. Pressure, Salinity=33.634°/oo, Second Degree Curve.

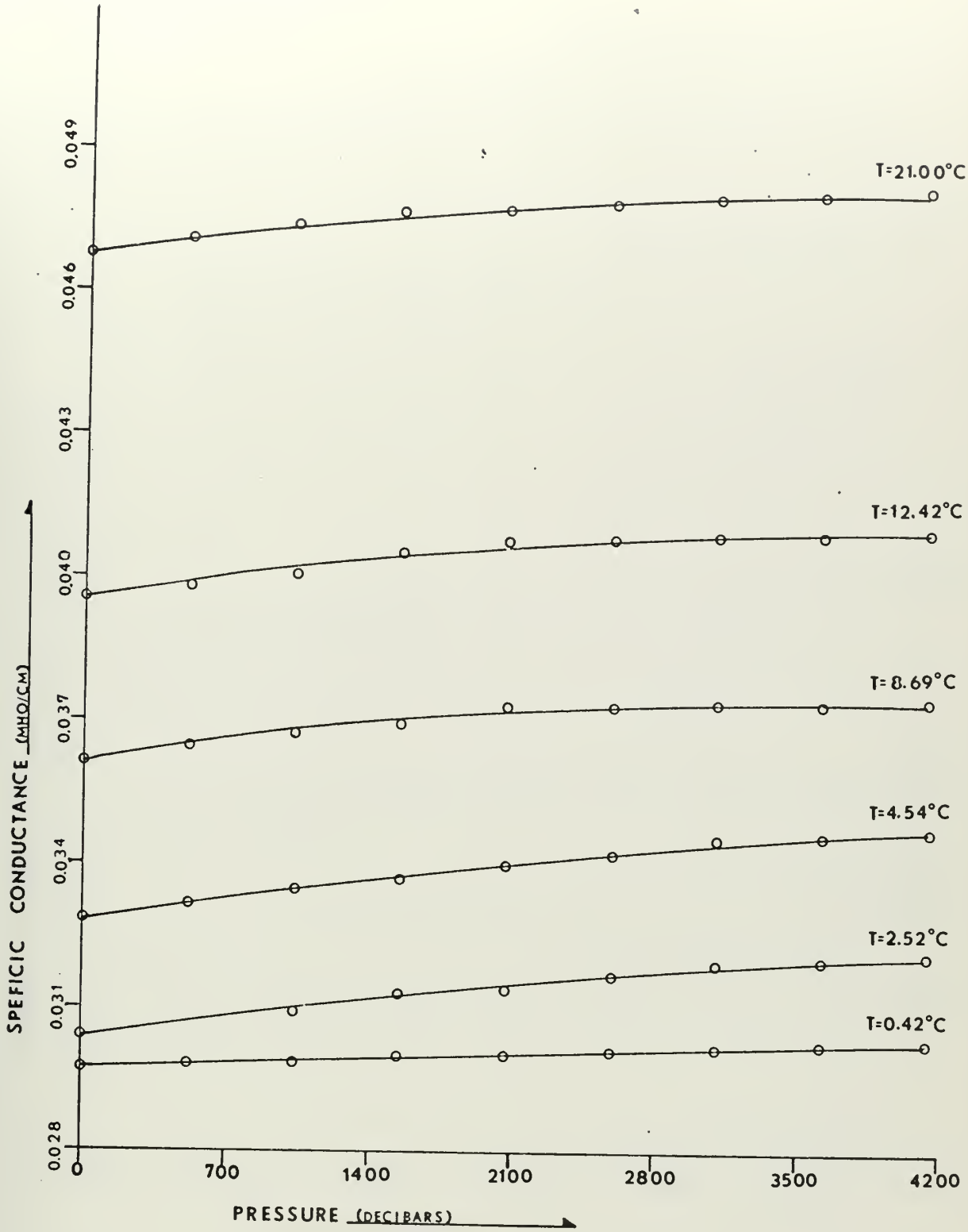

Figure 6. Specific Conductance vs. Pressure, Salinity=35.001°/oo, Second Degree Curve.

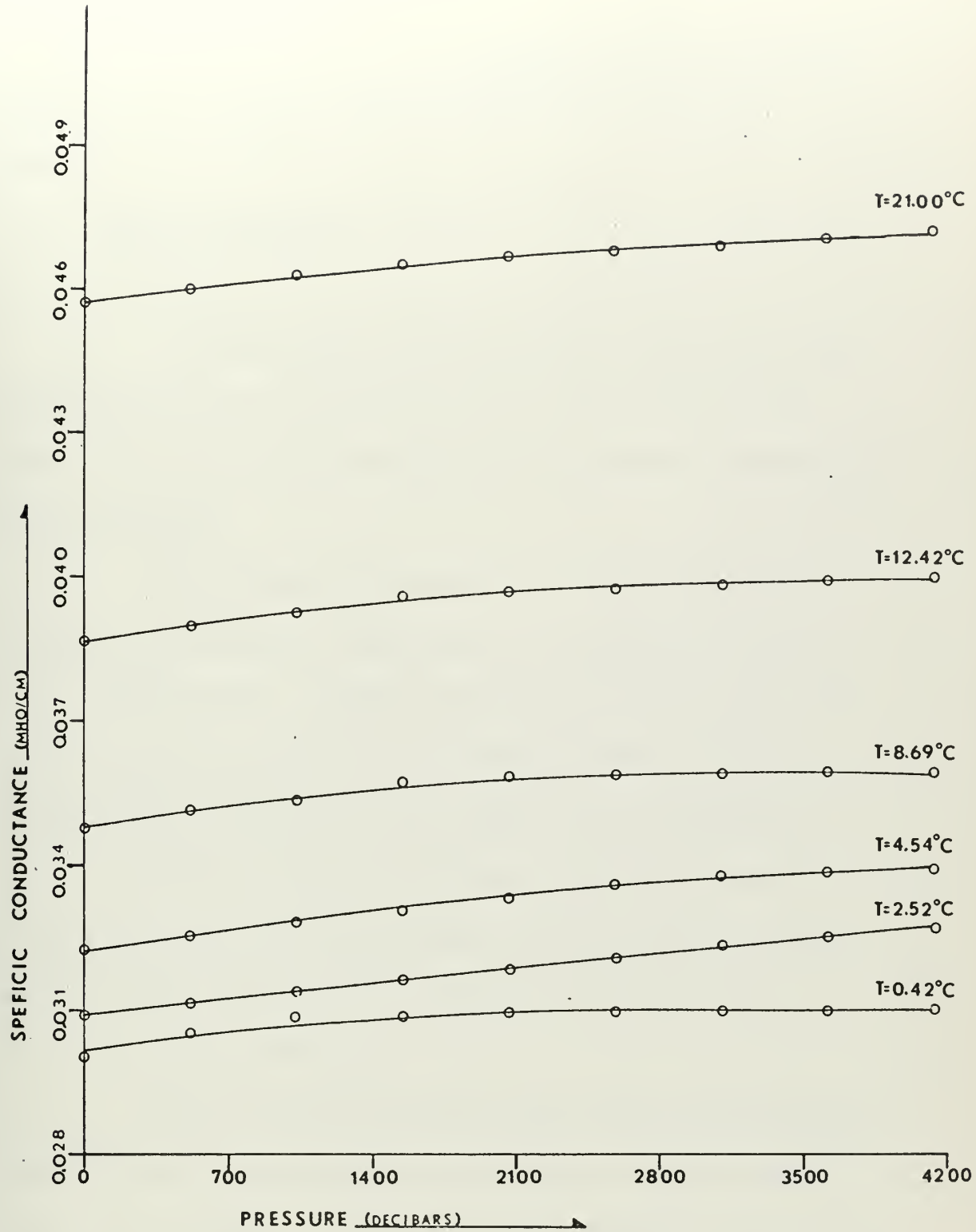

Figure 7. Specific Conductance vs. Pressure, Salinity=34.099°/oo, Second Degree Curve.

good agreement with comparable values reported by Ettle (1969) whose results were also 0.5% to 1.0% below those of Thomas et al. or Reeburgh.

2. Elevated Pressures

a. Hamon

Hamon (1958) reported linear pressure coefficients of the conductivity ratio for sea water of salinity 35.6°/oo at four temperatures. The pressure range considered by Hamon was 0 to 1,000 decibars above atmospheric.

Hamon made his measurements under nearly adiabatic conditions and then applied a correction for the conductivity increase due to adiabatic heating. Bradshaw and Schleicher (1965) suggested that significant heat was probably lost and this may explain why Hamon's results are about 15% lower than the results of this investigation.

Further comparison with Hamon's data is not possible since his data shows increasing resistance for both increasing temperature and pressure. The reverse is, of course, true in both cases.

b. Horne and Frysinger

Horne and Frysinger (1963) in their study concluded that the effect of pressure on conductivity of sea water is linear up to 6,890 decibars and independent of temperature in the range 0°C to 25°C. However, as has been previously shown, the pressure effect cannot accurately be described as linear in the range of pressures considered by Horne and Frysinger.

For purposes of comparison, values of specific conductance were computed using the salinities and pressures of this study in Horne and Frysinger's equation:

$$K_{P,T,Cl} = K_{1,T,Cl} + [(0.35 \pm 0.25) + (0.185 \pm 0.028)Cl]10^{-6}P \quad (11)$$

where pressure is in bars above atmospheric and chlorinity (Cl) is in parts per mille.

All mean values of specific conductances computed using the Horne and Frysinger equation were within 0.001 mho/cm of the observed value, and all observed values fall within the rather large deviation described by Horne and Frysinger.

c. Bradshaw and Schleicher

Bradshaw and Schleicher (1965) essentially duplicated the work of Horne and Frysinger. However, they reported their results as a polynomial for the fractional increase in conductivity ratio of specific conductance at pressure, P, to the specific conductance at atmospheric pressure. Their polynomial is first degree in salinity and third degree in temperature and pressure. Their equation was solved for the conductivity ratio. The computed ratio was about 0.5% below the observed conductivity ratio calculated from the present data. This corresponds to an equivalent salinity error of up to 0.19°/oo. This is a significant difference, but Anthony Amos of Lamont Dougherty Geological Observatory observed at a recent STD users conference sponsored by Bissett-Berman Corporation, that in situ salinity sensors may be in error by

as much as -0.02 to 0.15°/oo due to apparent pressure effects on the conductivity head (Bissett-Berman Corp., 1971).

The conductivity ratios calculated from the present data and the ratios computed using the Bradshaw and Schleicher equation have been plotted and representative plots are shown in Figures 8, 9, and 10.

The fractional increase in conductivity ratio, when computed using the Bradshaw and Schleicher equation, should be zero at atmospheric pressure. However, examination of their equation reveals that a residual of at least 4×10^{-4} remains. Thus, their equation does not behave well near atmospheric pressure. This residual at atmospheric pressure corresponds to an equivalent salinity error of about 0.1°/oo.

In order to avoid the problem of Bradshaw and Schleicher of significant error at pressures near atmospheric, an equation was developed that more nearly fits the physical constraints on conductivity ratio at atmospheric pressure. The equation developed has the form of:

$$T^{-1} \times \mathrm{Ln}(R) = A_1 + A_2(P-P_o) + A_2(P-P_o)^2 \qquad (12)$$

Where:

A_i	= coefficients at each temperature
T	= absolute temperature (°K)
$(P-P_o)$	= change in absolute pressure (decibars)
$\mathrm{Ln}(R)$	= natural logarithm of the conductivity ratio $\kappa(S,T,P)/\kappa(S,T,P_o)$
P_o	= reference pressure of one atmosphere (10.13 decibars)

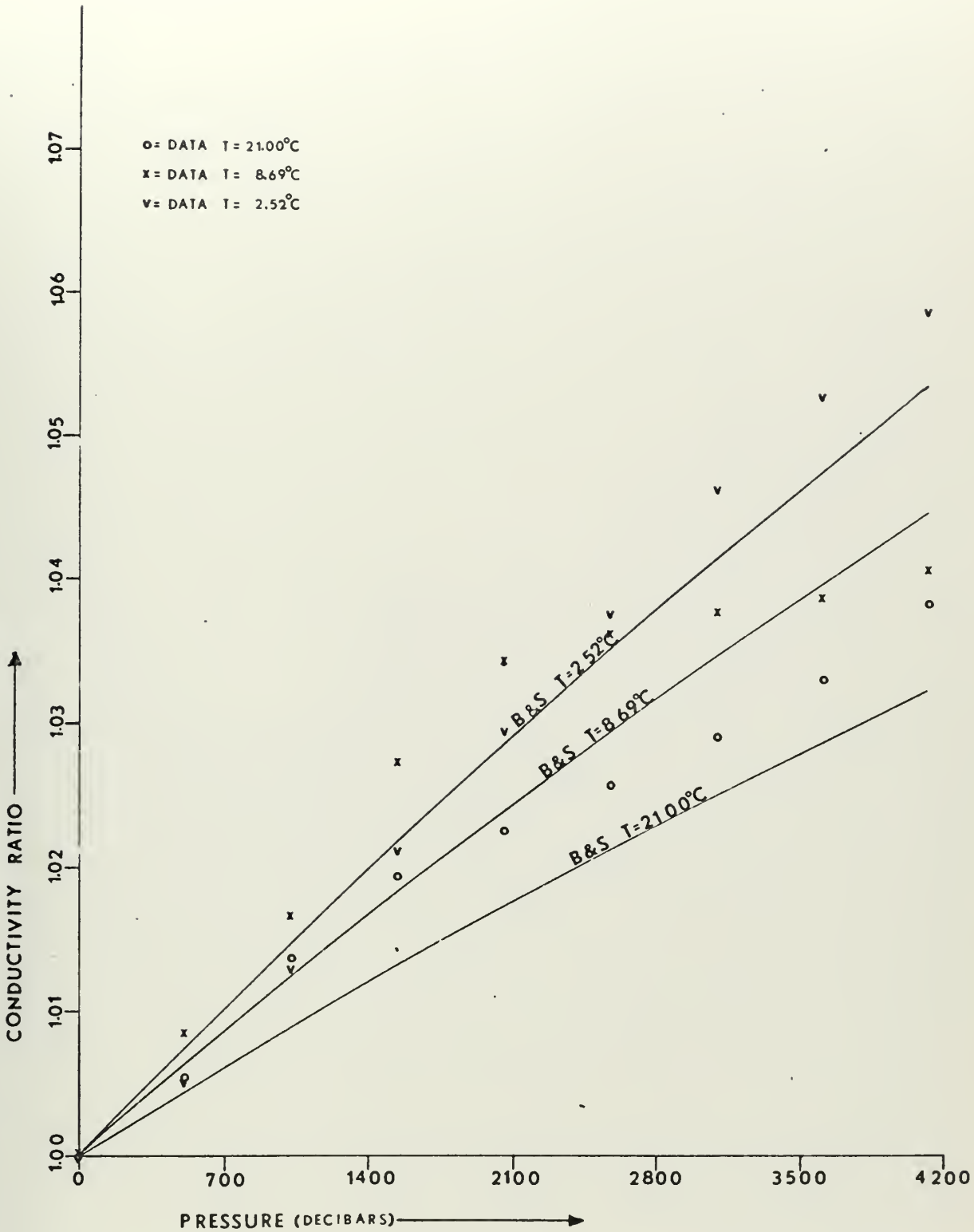

Figure 8. Conductivity Ratio vs. Pressure, Salinity=33.634°/oo.
Points: Present data, curve: Bradshaw and Schleicher.

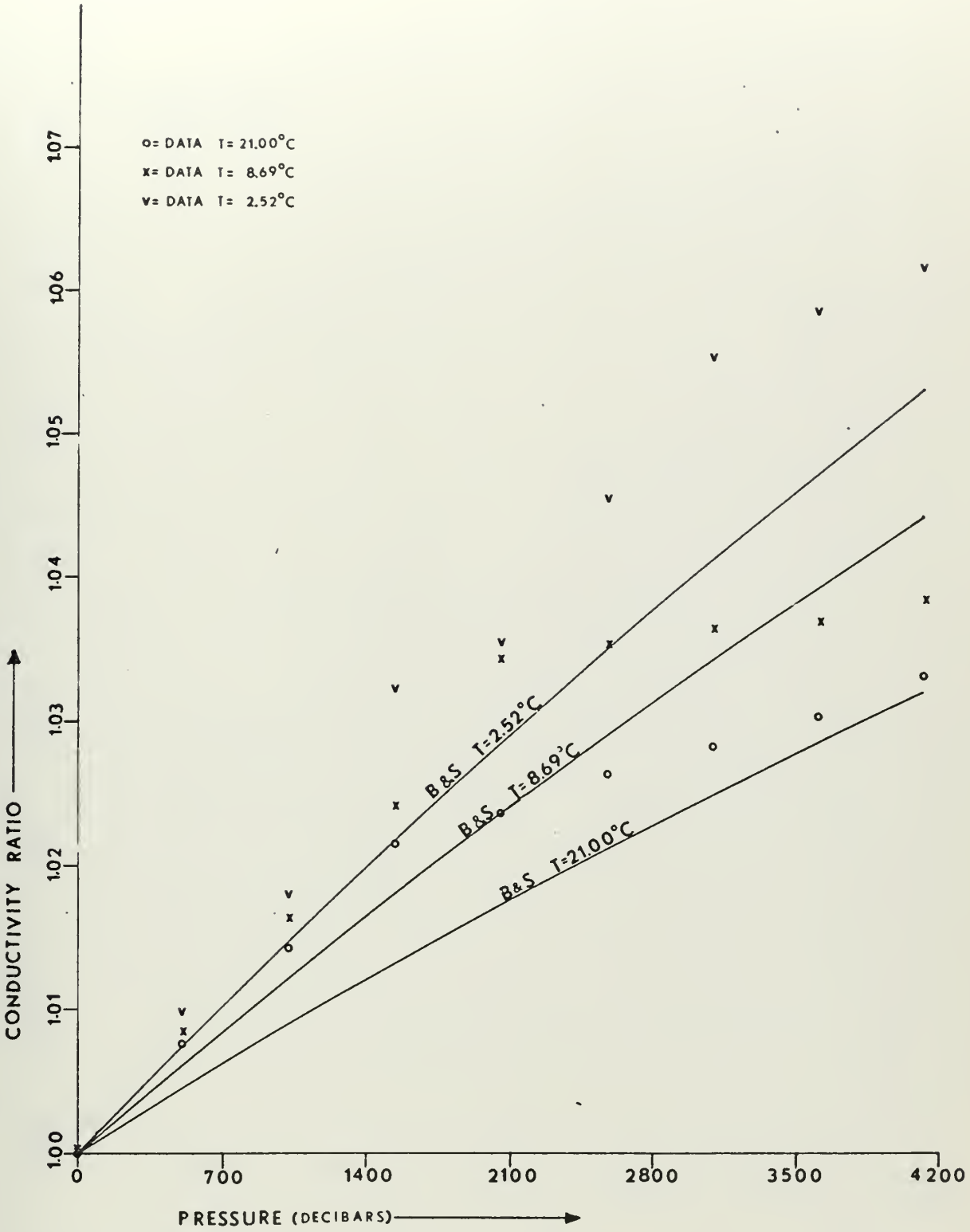

Figure 9. Conductivity Ratio vs. Pressure, Salinity=35.001°/oo.
Points: Present data, curve: Bradshaw and Schleicher.

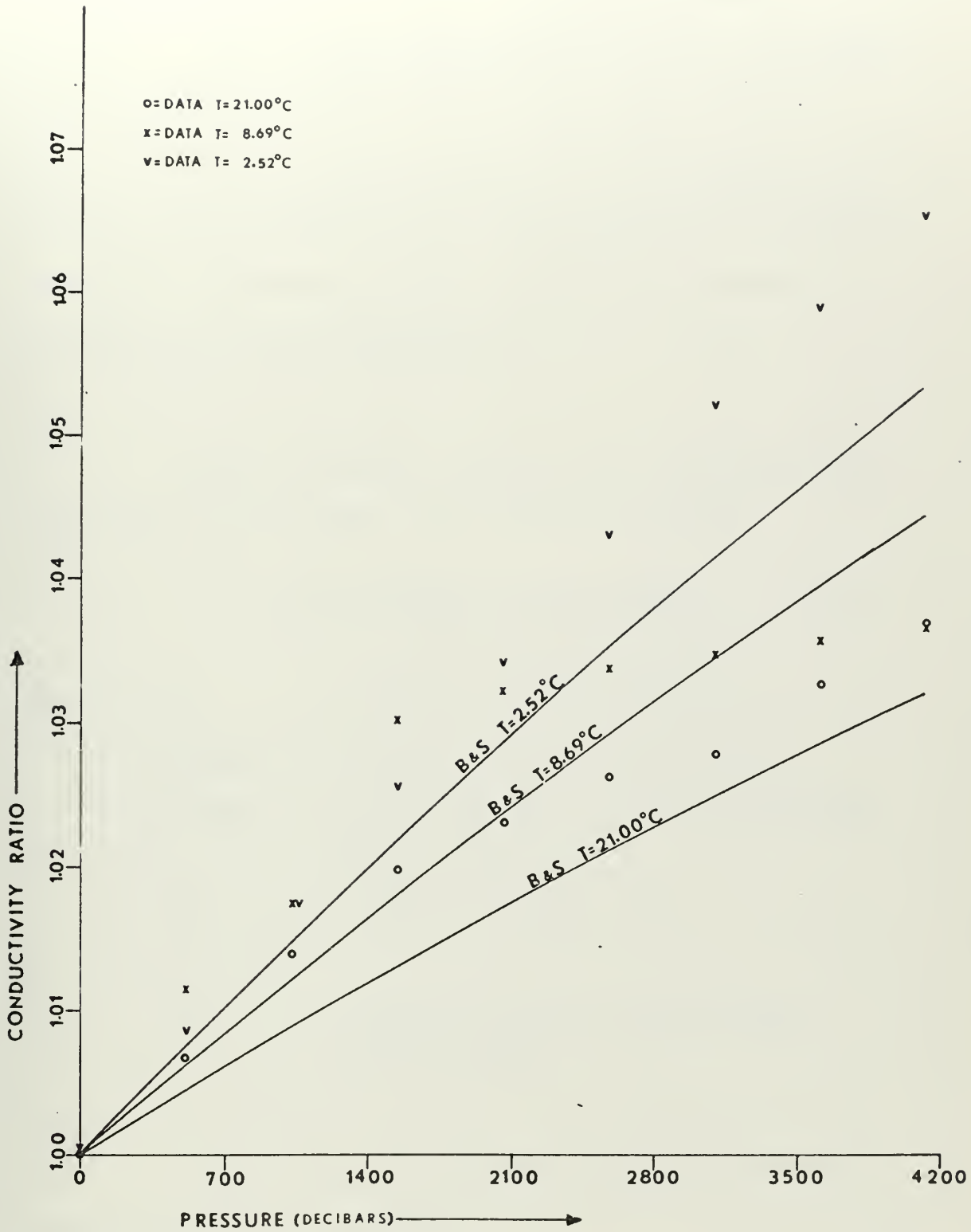

Figure 10. Conductivity Ratio vs. Pressure, Salinity=34.099°/oo.
Points: Present data, curve: Bradshaw and Schleicher.

This equation still has an ambiguity at atmospheric pressure of $e^{\pm 0.0001}$ This is obviously a significant improvement if the equation can be verified by experiment. This equation fits the conductivity ratios calculated from the present data with a standard deviation of about 1.4×10^{-5} in conductivity ratio which corresponds to an equivalent salinity error of less than $\pm 0.01^{o}/oo$. Values of the coefficients are shown in Table X, XI and XII (Appendix A).

Another, independent, equation that fits the present data equally well was also developed. This equation has the form:

$$(P-P_o)^{-1} \times LN(R) = B_1 + B_2T + B_3T^2 \qquad (13)$$

Where:

B_i = coefficients at each $(P-P_o)$

$(P-P_o)$ = change in absolute pressure (decibars)

$LN(R)$ = natural logarithm of the conductivity ratio $\kappa(S,T,P)/\kappa(S,T,P_o)$

T = absolute temperature (^{o}K)

P_o = reference pressure of one atmosphere (10.13 decibars)

Values of the coefficients for this equation are shown in Table XIII, XIV and XV (Appendix A).

d. Mays

Significant nonlinearities were found by Mays (1968) in the relationship between specific conductance and pressure. He was unable to conclude which degree polynomial to use to describe the pressure effect and none was reported. Consequently, no quantitative comparison was possible.

Qualitatively, Mays' data showed large deviations from linearity and occasionally maxima and minima were observed. These were not observed in this study nor have they been reported in earlier investigations.

e. Ettle

Ettle (1969) in his investigation of the pressure effect on conductivity of sea water reported a third degree polynomial in pressure for conductivity ratio that fit his data with a standard deviation of 0.05°/oo equivalent salinity error. His data was in fair agreement with the results of Bradshaw and Schleicher.

Conductivity ratios at three temperatures were computed (using the polynomial developed by Ettle) near corresponding temperatures and pressures of the present study. These computed ratios were then compared to conductivity ratios calculated from the observed specific conductances. The computed ratios were, in all cases, 0.2% to 0.8% below the observed ratios. This is not an unexpected result since Ettle's equation has no temperature or salinity dependence, and neither the

temperature nor salinity of the present data was exactly the same as those used by Ettle when he developed his equation.

A few randomly selected values of pressure, temperature and specific conductance from Ettle's data were used in both equations (12)and (13) developed in this investigation. Using Ettle's data, these equations produced errors in equivalent salinity of $0.008^{o}/oo$. Thus, equations (12) and (13) are at least partially verified, but more evaluation than has been done is necessary.

VI. CONCLUSIONS AND RECOMMENDATIONS

The specific conductivity of sea water at temperatures and salinities representative of the ocean, increases with increasing pressure. Mathematical relationships for the variations indicate that they are nonlinear. The most common method of previous investigations in fitting observed data has been by using polynomials of second or third degree. However, these polynomials, particularly that of Bradshaw and Schleicher, do not describe the relationship of conductivity and pressure adequately at pressures near atmospheric. Equations (12 and (13) were developed relating conductivity ratio, temperature and pressure. While neither equation is entirely satisfactory, they do at least describe the present data and the data of Ettle well. There is apparently a rather complex temperature-pressure effect on the conductivity of sea water, and although this effect

may be small, it can be significant, especially if accuracy to four significant figures is required for *in situ* measurements of salinity.

For future work, more detailed comparison of equations (12) and (13) developed in this study over a wider range of salinities is recommended, and more data at temperatures and pressures characteristic of the deep ocean would be useful. Further investigation of the temperature-pressure effect on conductivity is also recommended.

APPENDIX A. TABLES OF EXPERIMENTAL RESULTS

LIST OF TABLES

PRESSURE (decibars)	TEMPERATURE= 21.00°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 16.33°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 12.42°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.044777	0.040826	0.037523
517.7	0.045010	0.041110	0.037805
1035.5	0.045354	0.041363	0.038080
1553.2	0.045594	0.041628	0.038335
2070.9	0.045727	0.042049	0.038732
2588.7	0.045861	0.042186	0.038879
3106.4	0.045999	0.042253	0.038975
3624.1	0.046164	0.042323	0.039070
4141.8	0.046386	0.042622	0.039167

PRESSURE (decibars)	TEMPERATURE= 11.29°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 8.69°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 6.58°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.036748	0.034661	0.032506
517.7	0.037074	0.034931	0.032819
1035.5	0.037348	0.035191	0.033070
1553.2	0.037689	0.035531	0.033314
2070.9	0.037934	0.035753	0.033560
2588.7	0.037988	0.035815	0.033939
3106.4	0.038044	0.035862	0.034030
3624.1	0.038098	0.035895	0.034082
4141.8	0.038150	0.035959	0.034137

TABLE I. Experimental Results for Sea Water of Salinity 33.634°/oo

PRESSURE (decibars)	TEMPERATURE= 4.54°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 3.64°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 2.52°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.031309	0.030788	0.030015
517.7	0.031585	0.031143	0.030159
1035.5	0.031803	0.031313	0.030369
1553.2	0.032038	0.031632	0.030591
2070.9	0.032264	0.031840	0.030819
2588.7	0.032495	0.032155	0.031038
3106.4	0.032715	0.032314	0.031273
3624.1	0.032938	0.032353	0.031451
4141.8	0.033137	0.032477	0.031607

PRESSURE (decibars)	TEMPERATURE= 1.38°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE- 4.39°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 0.42°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.029030	0.032801	0.028938
517.7	0.029315	0.033284	0.029283
1035.5	0.029658	0.033488	0.029563
1553.2	0.029868	0.033606	0.029847
2070.9	0.029890	0.033658	0.030126
2588.7	0.029911	0.033671	0.030151
3106.4	0.029933	0.033696	0.030216
3624.1	0.029943	0.033705	0.030268
4141.8	0.029954	0.033715	0.030516

TABLE I (Continued). Experimental Results for Sea Water of Salinity 33.634°/oo

PRESSURE (decibars)	TEMPERATURE= 21.00°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 16.33°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 12.42°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.046814	0.041803	0.039658
517.7	0.047151	0.042186	0.039897
1035.5	0.047441	0.042439	0.040140
1553.2	0.047764	0.042809	0.040533
2070.9	0.047855	0.042881	0.040849
2588.7	0.047973	0.042997	0.040912
3106.4	0.048062	0.043070	0.040975
3624.1	0.048154	0.043188	0.041018
4141.8	0.048274	0.043330	0.041062

PRESSURE (decibars)	TEMPERATURE= 11.29°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 8.69°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE- 6.58°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.037261	0.036186	0.033966
517.7	0.037523	0.036464	0.034180
1035.5	0.037790	0.036733	0.034427
1553.2	0.038135	0.036992	0.034722
2070.9	0.038502	0.037331	0.035067
2588.7	0.038558	0.037366	0.035130
3106.4	0.038671	0.037402	0.035159
3624.1	0.038766	0.037417	0.035175
4141.8	0.038841	0.037471	0.035204

TABLE II. Experimental Results for Standard Sea Water of Salinity 35.001°/oo

PRESSURE (decibars)	TEMPERATURE= 4.54°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 3.64°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 2.52°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.032897	0.031356	0.030457
517.7	0.033192	0.031620	0.030728
1035.5	0.033464	0.031851	0.030957
1553.2	0.033741	0.032087	0.031352
2070.9	0.034008	0.032328	0.031440
2588.7	0.034296	0.032598	0.031717
3106.4	0.034574	0.032918	0.031987
3624.1	0.034648	0.033004	0.032075
5151.8	0.034751	0.033097	0.032163

PRESSURE (decibars)	TEMPERATURE= 1.38°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 4.39°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 0.42°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.030094	0.033819	0.029798
517.7	0.030380	0.034270	0.029860
1035.5	0.030659	0.034618	0.029878
1553.2	0.031003	0.034686	0.030018
2070.9	0.031203	0.034712	0.030061
2588.7	0.031213	0.034714	0.030158
3106.4	0.031237	0.034725	0.030211
3624.1	0.031273	0.034737	0.030283
4141.8	0.031297	0.034764	0.030320

TABLE II (Continued). Experimental Results for Standard Sea Water of Salinity 35.001°/oo

PRESSURE (decibars)	TEMPERATURE= 21.00°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 16.33°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 12.42°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.045727	0.041538	0.038615
517.7	0.046026	0.041960	0.038937
1035.5	0.046331	0.042227	0.039227
1553.2	0.046585	0.042622	0.039597
2070.9	0.046727	0.042857	0.039699
2588.7	0.046862	0.042951	0.039739
3106.4	0.046932	0.043021	0.039838
3624.1	0.047138	0.043141	0.039939
4141.8	0.047323	0.043378	0.040001

PRESSURE (decibars)	TEMPERATURE= 11.29°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 8.69°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 6.58°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.037489	0.034795	0.033044
517.7	0.037755	0.035168	0.033327
1035.5	0.038026	0.035361	0.033588
1553.2	0.038301	0.035766	0.033911
2070.9	0.038768	0.035831	0.034158
2588.7	0.038804	0.035879	0.034296
3106.4	0.038880	0.035910	0.034339
3624.1	0.038956	0.035943	0.034368
4141.8	0.039013	0.035975	0.034397

TABLE III. Experimental Results for Sea Water of Salinity 34.099°/oo

PRESSURE (decibars)	TEMPERATURE= 4.54°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 3.64°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 2.52°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.032251	0.031003	0.030865
517.7	0.032545	0.031261	0.031108
1035.5	0.032794	0.031512	0.031356
1553.2	0.033058	0.031744	0.031585
2070.9	0.033314	0.032055	0.031827
2588.7	0.033629	0.032226	0.032076
3106.4	0.033797	0.032648	0.032328
3624.1	0.033868	0.032689	0.032520
4141.8	0.033924	0.032779	0.032701

PRESSURE (decibars)	TEMPERATURE= 1.38°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 4.39°C SPECIFIC CONDUCTANCE (mho/cm)	TEMPERATURE= 0.42°C SPECIFIC CONDUCTANCE (mho/cm)
0.0	0.029734	0.033152	0.030036
517.7	0.030040	0.033658	0.030521
1035.5	0.030303	0.034022	0.030852
1553.2	0.030659	0.034036	0.030891
2070.9	0.030774	0.034127	0.030943
2588.7	0.030796	0.034221	0.030971
3106.4	0.030808	0.034259	0.030973
3624.1	0.030819	0.034479	0.030984
4141.8	0.030831	0.034596	0.031019

TABLE III (Continued). Experimental Results for Sea Water of Salinity 34.099°/oo

PRESSURE (decibars)	A_1	A_2	A_3	A_4
	2.5161×10^{-2}	7.7356×10^{-4}		
0.0	2.5477×10^{-2}	6.6721×10^{-4}	5.2275×10^{-6}	
	2.5462×10^{-2}	6.7625×10^{-4}	4.1132×10^{-6}	3.5093×10^{-8}
	2.5466×10^{-2}	7.7172×10^{-4}		
517.7	2.5758×10^{-2}	6.7375×10^{-4}	4.8155×10^{-6}	
	2.5749×10^{-2}	6.7883×10^{-4}	4.1897×10^{-6}	1.9706×10^{-8}
	2.5698×10^{-2}	7.7498×10^{-4}		
1035.5	2.6026×10^{-2}	6.6463×10^{-4}	5.4241×10^{-6}	
	2.6048×10^{-2}	6.5131×10^{-4}	7.0668×10^{-6}	-5.1730×10^{-8}
	2.5940×10^{-2}	7.7674×10^{-4}		
1553.2	2.6242×10^{-2}	6.7538×10^{-4}	4.9822×10^{-6}	
	2.6297×10^{-2}	6.4154×10^{-4}	9.1545×10^{-6}	-1.3139×10^{-7}
	2.6114×10^{-2}	7.8314×10^{-4}		
2070.9	2.6345×10^{-2}	7.0548×10^{-4}	3.8177×10^{-6}	
	2.6530×10^{-2}	5.9157×10^{-4}	1.7859×10^{-5}	-4.4216×10^{-7}
	2.6261×10^{-2}	7.8284×10^{-4}		
2588.7	2.6454×10^{-2}	7.1784×10^{-4}	3.1947×10^{-6}	
	2.6532×10^{-2}	6.6983×10^{-4}	9.1136×10^{-6}	-1.8639×10^{-7}
	2.6368×10^{-2}	7.8212×10^{-4}		
3106.4	2.6578×10^{-2}	7.1159×10^{-4}	3.4669×10^{-6}	
	2.6598×10^{-2}	6.9880×10^{-4}	5.0436×10^{-6}	-4.9651×10^{-8}

TABLE IV. Coefficients of the Polynomial $K(S,T,P)=A_1+A_2T+A_3T^2+A_4T^3$ for Sea Water of Salinity 33.634°/oo.

PRESSURE (decibars)	A_1	A_2	A_3	A_4
	2.6431×10^{-2}	7.8457×10^{-4}		
3624.1	2.6666×10^{-2}	7.0564×10^{-4}	3.8795×10^{-6}	
	2.6646×10^{-2}	7.1762×10^{-4}	2.4030×10^{-6}	4.6495×10^{-8}
	2.6520×10^{-2}	7.8956×10^{-4}		
4141.8	2.6825×10^{-2}	6.8690×10^{-4}	5.0462×10^{-6}	
	2.6866×10^{-2}	6.6223×10^{14}	8.0883×10^{-6}	-9.5798×10^{-8}

TABLE IV (Continued). Coefficients of the Plynomial $K(S,T,P)=A_1+A_2T+A_3T^2+A_4T^3$ for Sea Water of Salinity 33.634°/oo.

PRESSURE (decibars)	A_1	A_2	A_3	A_4
0.0	2.5972×10^{-2}	8.2024×10^{-4}		
	2.6284×10^{-2}	7.1538×10^{-4}	5.1542×10^{-6}	
	2.6030×10^{-2}	8.7174×10^{-4}	-1.4121×10^{-5}	6.0699×10^{-7}
517.7	2.6207×10^{-2}	8.2588×10^{-4}		
	2.6499×10^{-2}	7.2766×10^{-4}	4.8279×10^{-6}	
	2.6175×10^{-2}	9.2699×10^{-4}	-1.9745×10^{-5}	7.7380×10^{-7}
1035.5	2.6419×10^{-2}	8.3014×10^{-4}		
	2.6670×10^{-2}	7.4581×10^{-4}	4.1452×10^{-6}	
	2.6260×10^{-2}	9.9836×10^{-4}	-2.6987×10^{-5}	9.8037×10^{-7}
1553.2	2.6654×10^{-2}	8.3685×10^{-4}		
	2.6885×10^{-2}	7.5922×10^{-4}	3.8162×10^{-6}	
	2.6521×10^{-2}	9.8309×10^{-4}	-2.3782×10^{-5}	8.6907×10^{-7}
2070.9	2.6845×10^{-2}	8.3794×10^{-4}		
	2.6930×10^{-2}	8.0953×10^{-4}	1.3962×10^{-6}	
	2.6530×10^{-2}	1.0555×10^{-3}	-2.8923×10^{-5}	9.5476×10^{-7}
2588.7	2.6984×10^{-2}	8.3508×10^{-4}		
	2.7094×10^{-2}	7.9810×10^{-4}	1.8177×10^{-6}	
	2.6639×10^{-2}	1.0780×10^{-3}	-3.2692×10^{-5}	1.0867×10^{-6}

TABLE V. Coefficients of the Polynomial $\kappa(S,T,P)=A_1+A_2T+A_3T^2+A_4T^3$ for Standard Sea Water of Salinity 35.001°/oo.

PRESSURE (decibars)	A_1	A_2	A_3	A_4
	2.7127×10^{-2}	8.3121×10^{-4}		
3106.4	2.7242×10^{-2}	7.9251×10^{-4}	1.9021×10^{-6}	
	2.6721×10^{-2}	1.1134×10^{-3}	-3.7655×10^{-5}	1.2457×10^{-6}
	2.7173×10^{-2}	8.3324×10^{-4}		
3624.1	2.7307×10^{-2}	7.8818×10^{-4}	2.2148×10^{-6}	
	2.6808×10^{-2}	1.0955×10^{-4}	-3.5672×10^{-5}	1.1931×10^{-6}
	2.7216×10^{-2}	8.3680×10^{-4}		
4141.8	2.7361×10^{-2}	7.8779×10^{-4}	2.4091×10^{-6}	
	2.6860×10^{-2}	1.0967×10^{-3}	-3.5567×10^{-5}	1.1990×10^{-6}

TABLE V (Continued) Coefficients of the Polynomial $K(S,T,P)=A_1+A_2T+A_3T^2+A_4T^3$ for Standard Sea Water of Salinity 35.001°/oo

PRESSURE (decibars)	A_1	A_2	A_3	A_4
0.0	2.5774×10^{-2}	7.8282×10^{-4}		
	2.6299×10^{-2}	6.0635×10^{-4}	8.6742×10^{-6}	
	2.6572×10^{-2}	4.3836×10^{-4}	2.9383×10^{-5}	-6.5213×10^{-7}
517.7	2.6121×10^{-2}	7.8171×10^{-4}		
	2.6663×10^{-2}	5.9943×10^{-4}	8.9598×10^{-6}	
	2.6997×10^{-2}	3.9377×10^{-4}	3.4311×10^{-5}	-7.9833×10^{-7}
1035.5	2.6395×10^{-2}	7.8172×10^{-4}		
	2.6964×10^{-2}	5.9003×10^{-4}	9.4222×10^{-6}	
	2.7308×10^{-2}	3.7868×10^{-4}	3.5477×10^{-5}	-8.2047×10^{-7}
1553.2	2.6592×10^{-2}	7.9026×10^{-4}		
	2.7084×10^{-2}	6.2476×10^{-4}	8.1350×10^{-6}	
	2.7462×10^{-2}	3.9228×10^{-4}	3.6793×10^{-5}	-9.0246×10^{-7}
2070.9	2.6764×10^{-2}	7.9273×10^{-4}		
	2.7189×10^{-2}	6.4985×10^{-4}	7.0233×10^{-6}	
	2.7547×10^{-2}	4.2911×10^{-4}	3.4233×10^{-5}	-8.5685×10^{-7}
2588.7	2.6898×10^{-2}	7.9041×10^{-4}		
	2.7332×10^{-2}	6.4483×10^{-4}	7.1560×10^{-6}	
	2.7577×10^{-2}	4.9372×10^{-4}	2.5784×10^{-5}	-5.8659×10^{-7}

TABLE VI. Coefficients of the Polynomial $\kappa(S,T,P)=A_1+A_2T+A_3T^2+A_4T^3$ for Sea Water of Salinity 34.099°/oo

PRESSURE (decibars)	A_1	A_2	A_3	A_4
	2.7033×10^{-2}	7.8683×10^{-4}		
3106.4	2.7456×10^{-2}	6.4469×10^{-4}	6.9869×10^{-6}	
	2.7625×10^{-2}	5.4078×10^{-4}	1.9796×10^{-5}	-4.0336×10^{-7}
	2.7088×10^{-2}	7.9174×10^{-4}		
3624.1	2.7536×10^{-2}	6.4102×10^{-4}	7.4084×10^{-6}	
	2.7656×10^{-2}	5.6723×10^{-4}	1.6505×10^{-5}	-2.8645×10^{-7}
	2.7131×10^{-2}	7.9787×10^{-4}		
4141.8	2.7614×10^{-2}	6.3549×10^{-4}	7.9819×10^{-6}	
	2.7736×10^{-2}	5.6083×10^{-4}	1.7186×10^{-5}	-2.8983×10^{-7}

TABLE VI (Continued). Coefficients of the Polynomial $K(S,T,P)=A_1+A_2T+A_3T^2+A_4T^3$ for Sea Water of Salinity 34.099°/oo

TEMPERATURE (°C)	B_1	B_2	B_3	B_4
21.00	4.1889×10^{-2}	3.6878×10^{-7}		
	4.1795×10^{-2}	5.2467×10^{-7}	-3.7638×10^{-11}	
	4.1743×10^{-2}	7.4039×10^{-7}	-1.7576×10^{-10}	2.2232×10^{-14}
16.33	3.7941×10^{-2}	4.2361×10^{-7}		
	3.7798×10^{-2}	6.6048×10^{-7}	-5.7189×10^{-11}	
	3.7797×10^{-2}	6.6366×10^{-7}	-5.9226×10^{-11}	3.2794×10^{-16}
12.42	3.4660×10^{-2}	4.0898×10^{-7}		
	3.4476×10^{-2}	7.1425×10^{-7}	-7.3703×10^{-11}	
	3.4510×10^{-2}	5.7460×10^{-7}	1.5712×10^{-11}	-1.4392×10^{-14}
11.29	3.3984×10^{-2}	3.3381×10^{-7}		
	3.3731×10^{-2}	7.5169×10^{-7}	-1.0089×10^{-10}	
	3.3721×10^{-2}	7.9500×10^{-7}	-1.2862×10^{-10}	4.4634×10^{-15}
8.69	3.1863×10^{-2}	3.1263×10^{-7}		
	3.1629×10^{-2}	7.0084×10^{-7}	-9.3730×10^{-11}	
	3.1627×10^{-2}	7.0795×10^{-7}	-9.8281×10^{-11}	7.3258×10^{-16}
6.58	2.9638×10^{-2}	4.1388×10^{-7}		
	2.9466×10^{-2}	6.9791×10^{-7}	-6.8576×10^{-11}	
	2.9525×10^{-2}	4.5478×10^{-7}	8.7094×10^{-11}	-2.5056×10^{-14}

TABLE VII. Coefficients of the Polynomial $\kappa(S,T,P)=B_1+B_2P+B_3P^2+B_4P^3$ for Sea Water of Salinity 33.634°/oo

TEMPERATURE (°C)	B_1	B_2	B_3	B_4
	2.8343×10^{-2}	4.3961×10^{-7}		
4.54	2.8320×10^{-2}	4.7844×10^{-7}	-9.3741×10^{-12}	
	2.8318×10^{-2}	4.8708×10^{-7}	-1.4911×10^{-11}	8.9122×10^{-16}
	2.7957×10^{-2}	4.0268×10^{-7}		
3.64	2.7841×10^{-2}	5.9481×10^{-7}	-4.6386×10^{-11}	
	2.7896×10^{-2}	3.6321×10^{-7}	1.0190×10^{-10}	-2.3868×10^{-14}
	2.6980×10^{-2}	4.0238×10^{-7}		
2.52	2.6975×10^{-2}	4.1113×10^{-7}	-2.1131×10^{-12}	
	2.7011×10^{-2}	2.6313×10^{-7}	9.2645×10^{-11}	-1.5252×10^{-14}
	2.6311×10^{-2}	1.9870×10^{-7}		
1.38	2.6064×10^{-2}	6.0711×10^{-7}	-9.8607×10^{-11}	
	2.6000×10^{-2}	8.7643×10^{-7}	-2.7105×10^{-10}	2.7756×10^{-14}
	3.0154×10^{-2}	1.7382×10^{-7}		
4.39	2.9922×10^{-2}	5.5784×10^{-7}	-9.2716×10^{-11}	
	2.9829×10^{-2}	9.4440×10^{-7}	-3.4022×10^{-10}	3.9838×10^{-14}
	2.6154×10^{-2}	3.5009×10^{-7}		
0.42	2.5960×10^{-2}	6.7019×10^{-7}	-7.7283×10^{-11}	
	2.5904×10^{-2}	9.0387×10^{-7}	-2.2691×10^{-10}	2.4083×10^{-14}

TABLE VII (Continued). Coefficients of the Polynomial $K(S,T,P)=B_1+B_2P+B_3P^2+B_4P3$ for Sea Water of Salinity 33.634°/oo

TEMPERATURE (°C)	B_1	B_2	B_3	B_4
	4.4034×10^{-2}	3.3162×10^{-7}		
21.00	4.3842×10^{-2}	6.5042×10^{-7}	-7.6970×10^{-11}	
	4.3793×10^{-2}	8.5441×10^{-7}	-2.0758×10^{-11}	2.1023×10^{-14}
	3.9040×10^{-2}	3.4010×10^{-7}		
16.33	3.8848×10^{-2}	6.5840×10^{-7}	-7.6850×10^{-11}	
	3.8785×10^{-2}	9.2099×10^{-7}	-2.4498×10^{-11}	2.7062×10^{-14}
	3.6825×10^{-2}	3.5499×10^{-7}		
12.42	3.6584×10^{-2}	7.5498×10^{-7}	-9.6571×10^{-11}	
	3.6618×10^{-2}	6.1048×10^{-7}	-4.0559×10^{-11}	-1.4891×10^{-14}
	3.4412×10^{-2}	3.9383×10^{-7}		
11.29	3.4203×10^{-2}	7.3917×10^{-7}	-8.3380×10^{-11}	
	3.4230×10^{-2}	6.3218×10^{-7}	-1.4876×10^{-11}	-1.1026×10^{-14}
	3.3393×10^{-2}	3.1252×10^{-7}		
8.69	3.3149×10^{-2}	7.1722×10^{-7}	-9.7709×10^{-11}	
	3.3159×10^{-2}	6.7452×10^{-7}	-7.0371×10^{-11}	-4.4003×10^{-15}
	3.1127×10^{-2}	3.1583×10^{-7}		
6.58	3.0892×10^{-2}	7.0457×10^{-7}	-9.3856×10^{-11}	
	3.0932×10^{-2}	5.3892×10^{-7}	1.2207×10^{-11}	-1.7072×10^{-14}

TABLE VIII. Coefficients of the Polynomial $K(S,T,P)=B_1+B_2P+B_3P^2+B_4P^3$ for Standard Sea Water of Salinity 35.001°/oo

TEMPERATURE (°C)	B_1	B_2	B_3	B_4
	2.9982×10^{-2}	4.6867×10^{-7}		
4.54	2.9860×10^{-2}	6.7036×10^{-7}	-4.8696×10^{-11}	
	2.9912×10^{-2}	4.5471×10^{-7}	8.9382×10^{-11}	-2.2225×10^{-14}
	2.8400×10^{-2}	4.4294×10^{-7}		
3.64	2.8327×10^{-2}	5.6495×10^{-7}	-2.9458×10^{-11}	
	2.8380×10^{-2}	3.4357×10^{-7}	1.1229×10^{-10}	-2.2815×10^{-14}
	2.7545×10^{-2}	4.2775×10^{-7}		
2.52	2.7428×10^{-2}	6.2055×10^{-7}	-4.6549×10^{-11}	
	2.7460×10^{-2}	4.8922×10^{-7}	3.7542×10^{-11}	-1.3535×10^{-14}
	2.7338×10^{-2}	2.8511×10^{-7}		
1.38	2.7072×10^{-2}	7.2629×10^{-7}	-1.0652×10^{-10}	
	2.7055×10^{-2}	7.9638×10^{-7}	-1.5140×10^{-10}	7.2236×10^{-15}
	3.1199×10^{-2}	1.7471×10^{-7}		
4.39	3.0942×10^{-2}	5.9949×10^{-7}	-1.0256×10^{-10}	
	3.0824×10^{-2}	1.0893×10^{-7}	-4.1614×10^{-10}	5.0474×10^{-14}
	2.6787×10^{-2}	1.3414×10^{-7}		
0.42	2.6781×10^{-2}	1.4430×10^{-7}	-2.4531×10^{-12}	
	2.6799×10^{-2}	7.1395×10^{-8}	4.4227×10^{-11}	-7.5136×10^{-15}

TABLE VIII (Continued). Coefficients of the Polynomial $K(S,T,P)=B_1+B_2P+B_3P^2+B_4P3$ for Standard Sea Water of Salinity 35.001°/oo

TEMPERATURE (°C)	B_1	B_2	B_3	B_4
21.00	4.2881×10^{-2}	3.6049×10^{-7}		
	4.2763×10^{-2}	5.5602×10^{-7}	-4.7207×10^{-11}	
	4.2703×10^{-2}	8.0618×10^{-7}	-2.0738×10^{-10}	2.5781×10^{-14}
16.33	3.8778×10^{-2}	4.1255×10^{-7}		
	3.8571×10^{-2}	7.5529×10^{-7}	-8.2749×10^{-11}	
	3.8512×10^{-2}	1.0029×10^{-7}	-2.4132×10^{-10}	2.5524×10^{-14}
12.42	3.5849×10^{-2}	3.1910×10^{-7}		
	3.5629×10^{-2}	6.8398×10^{-7}	-8.8097×10^{-11}	
	3.5584×10^{-2}	8.7061×10^{-7}	-2.0759×10^{-10}	1.9233×10^{-14}
11.29	3.4649×10^{-2}	3.8351×10^{-7}		
	3.4423×10^{-2}	7.5731×10^{-7}	-9.0249×10^{-11}	
	3.4462×10^{-2}	5.9084×10^{-7}	1.1724×10^{-11}	-1.6414×10^{-14}
8.69	3.2075×10^{-2}	2.6562×10^{-7}		
	3.1819×10^{-2}	6.9057×10^{-7}	-1.0260×10^{-10}	
	3.1777×10^{-2}	8.6346×10^{-7}	-2.1330×10^{-10}	1.7818×10^{-14}
6.58	3.0242×10^{-2}	3.3545×10^{-7}		
	3.0000×10^{-2}	7.3488×10^{-7}	-9.6437×10^{-11}	
	3.0023×10^{-2}	6.4133×10^{-7}	-3.6539×10^{-11}	-9.6412×10^{-15}

TABLE IX. Coefficients of the Polynomial $K(S,T,P)=B_1+B_2P+B_3P^2+B_4P^3$ for Sea Water of Salinity 34.099°/oo

TEMPERATURE (°C)	B_1	B_2	B_3	B_4
	2.9360×10^{-2}	4.2610×10^{-7}		
4.54	2.9209×10^{-2}	6.7496×10^{-7}	-6.0085×10^{-11}	
	2.9266×10^{-2}	4.3816×10^{-7}	9.1535×10^{-11}	-2.4405×10^{-14}
	2.8044×10^{-2}	4.5534×10^{-7}		
3.64	2.7966×10^{-2}	5.8489×10^{-7}	-3.1278×10^{-11}	
	2.8026×10^{-2}	3.3493×10^{-7}	1.2876×10^{-10}	-2.5760×10^{-14}
	2.7884×10^{-2}	4.5130×10^{-7}		
2.52	2.7854×10^{-2}	5.0142×10^{-7}	-1.2100×10^{-11}	
	2.7871×10^{-2}	4.2880×10^{-7}	3.4401×10^{-11}	-7.4848×10^{-15}
	2.7005×10^{-2}	2.5333×10^{-7}		
1.38	2.6729×10^{-2}	7.0936×10^{-7}	-1.1010×10^{-10}	
	2.6700×10^{-2}	8.3307×10^{-7}	-1.8931×10^{-10}	1.2750×10^{-14}
	3.0468×10^{-2}	2.8648×10^{-7}		
4.39	3.0314×10^{-2}	5.4114×10^{-7}	-6.1486×10^{-11}	
	3.0177×10^{-2}	1.1129×10^{-7}	-4.2759×10^{-10}	5.8928×10^{-14}
	2.7422×10^{-2}	1.8167×10^{-7}		
0.42	2.7170×10^{-2}	1.0036×10^{-7}	-1.0109×10^{-10}	
	2.7053×10^{-2}	1.0846×10^{-7}	-4.1114×10^{-10}	4.9905×10^{-14}

TABLE IX.(Continued). Coefficients of the Polynomial $K(S,T,P)=B_1+B_2P+B_3P^2+B_4P^3$ for Sea Water of Salinity 34.099°/oo

TEMPERATURE (°K)	A_1	A_2	A_3
294.16	2.102×10^{-3}	-6.890×10^{-6}	2.719×10^{-9}
289.49	-2.472×10^{-6}	5.970×10^{-8}	-5.293×10^{-12}
285.58	-4.525×10^{-6}	7.144×10^{-8}	-7.482×10^{-12}
284.45	-1.494×10^{-6}	7.708×10^{-8}	-1.040×10^{-11}
281.85	-3.362×10^{-6}	7.732×10^{-8}	-1.040×10^{-11}
279.74	-4.398×10^{-6}	8.316×10^{-8}	-8.328×10^{-12}
277.70	1.435×10^{-6}	6.063×10^{-8}	-1.564×10^{-12}
276.80	-5.819×10^{-6}	7.602×10^{-8}	-6.126×10^{-12}
275.68	-5.233×10^{-6}	5.506×10^{-8}	-6.202×10^{-12}
274.54	4.922×10^{-6}	8.355×10^{-8}	-1.359×10^{-11}
277.55	1.458×10^{-5}	6.647×10^{-8}	-1.106×10^{-11}
273.58	3.327×10^{-6}	9.287×10^{-8}	-1.088×10^{-11}

TABLE X. Coefficients of the Equation $T^{-1} \times \ln(R) = A_1 + A_2(P-P_o)^2$ for Sea Water of Salinity 33.634°/oo

TEMPERATURE (°K)	A_1	A_2	A_3
294.16	-2.228×10^{-6}	4.997×10^{-8}	-5.962×10^{-12}
289.49	4.067×10^{-6}	5.795×10^{-8}	-6.834×10^{-12}
285.58	-6.788×10^{-6}	7.108×10^{-8}	-9.144×10^{-12}
284.45	-5.561×10^{-6}	7.475×10^{-8}	-8.527×10^{-12}
281.85	-3.693×10^{-6}	7.550×10^{-8}	-1.033×10^{-11}
279.74	-8.118×10^{-6}	8.003×10^{-8}	-1.071×10^{-11}
277.70	-4.157×10^{-6}	7.965×10^{-8}	-6.038×10^{-12}
276.80	-3.429×10^{-6}	7.121×10^{-8}	-3.995×10^{-12}
275.68	-3.526×10^{-6}	8.090×10^{-8}	-6.324×10^{-12}
274.54	-2.575×10^{-6}	9.580×10^{-8}	-1.410×10^{-11}
277.55	1.438×10^{-5}	6.906×10^{-8}	-1.183×10^{-11}
273.58	-2.239×10^{-6}	1.965×10^{-8}	-3.695×10^{-13}

TABLE XI. Coefficients of the equation $T^{-1} \times \ln(R) = A_1 + A_2(P-P_o) + A_3(P-P_o)$ for Standard Sea Water of Salinity 35.001°/oo

TEMPERATURE (°K)	A_1	A_2	A_3
294.16	2.881×10^{-6}	4.394×10^{-8}	-3.816×10^{-12}
289.49	3.061×10^{-6}	6.685×10^{-8}	-7.431×10^{-12}
285.58	1.492×10^{-6}	6.637×10^{-8}	-8.607×10^{-12}
284.45	-6.308×10^{-6}	7.601×10^{-8}	-9.136×10^{-12}
281.85	2.780×10^{-6}	7.584×10^{-8}	-1.130×10^{-11}
279.74	-4.838×10^{-6}	8.593×10^{-8}	-1.135×10^{-11}
277.70	-4.761×10^{-6}	8.182×10^{-8}	-7.471×10^{-12}
276.80	-4.384×10^{-6}	7.460×10^{-8}	-4.288×10^{-12}
275.68	-1.351×10^{-6}	6.494×10^{-8}	-1.952×10^{-12}
274.54	-3.449×10^{-7}	9.483×10^{-8}	-1.475×10^{-11}
277.55	1.911×10^{-5}	6.393×10^{-8}	-7.381×10^{-12}
273.58	1.798×10^{-5}	7.980×10^{-8}	-1.346×10^{-11}

TABLE XII. Coefficients of the Equation $T^{-1} \times \ln(R) = A_1 + A_2(P-P_o) + A_3(P-P_o)^2$ for Sea Water of Salinity 34.099°/oo

$(P-P_o)$ (decibars)	B_1	B_2	B_3
507.6	-3.636×10^{-3}	2.693×10^{-5}	-4.950×10^{-8}
1025.3	-3.177×10^{-3}	2.341×10^{-5}	-4.283×10^{-8}
1543.1	-4.010×10^{-3}	2.918×10^{-5}	-5.283×10^{-8}
2060.8	-4.784×10^{-3}	3.447×10^{-5}	-6.185×10^{-8}
2578.5	-5.008×10^{-3}	3.599×10^{-5}	-6.444×10^{-8}
3096.2	-4.389×10^{-3}	3.158×10^{-5}	-5.661×10^{-8}
3614.0	-3.959×10^{-3}	2.849×10^{-5}	-5.109×10^{-8}
4131.7	-3.521×10^{-3}	2.346×10^{-5}	-4.216×10^{-8}

TABLE XIII. Coefficients of the Equation $(P-P_o)^{-1} \times \ln(R) = B_1 + B_2T + B_3T^2$ for Sea Water of Salinity 33.634°/oo

$(P-P_o)$ (decibars)	B_1	B_2	B_3
507.6	-7.582×10^{-3}	5.438×10^{-5}	-9.722×10^{-8}
1025.3	-8.070×10^{-3}	5.765×10^{-5}	-1.027×10^{-7}
1543.1	-7.434×10^{-3}	5.312×10^{-5}	-9.465×10^{-8}
2060.8	-8.625×10^{-3}	6.144×10^{-5}	-1.092×10^{-7}
2578.5	-6.849×10^{-3}	4.890×10^{-5}	-8.707×10^{-8}
3096.2	-5.846×10^{-3}	4.181×10^{-5}	-7.457×10^{-8}
3614.0	-5.008×10^{-3}	3.583×10^{-5}	-6.393×10^{-8}
4131.7	-4.549×10^{-3}	3.254×10^{-5}	-5.805×10^{-8}

TABLE XIV. Coefficients of the Equation $(P-P_o)^{-1} \ln(R) = B_1 + B_2T + B_3T^2$ for Standard Sea Water of Salinity 35.001°/oo

$(P-P_o)$ (decibars)	B_1	B_2	B_3
507.6	-4.612×10^{-4}	4.698×10^{-6}	-1.058×10^{-8}
1025.3	-1.813×10^{-3}	1.392×10^{-5}	-2.633×10^{-8}
1543.1	-4.849×10^{-3}	3.506×10^{-5}	-6.311×10^{-8}
2060.8	-5.569×10^{-3}	4.002×10^{-5}	-7.164×10^{-8}
2578.5	-4.893×10^{-3}	3.520×10^{-5}	-6.309×10^{-8}
3096.2	-4.408×10^{-3}	3.174×10^{-5}	-5.694×10^{-8}
3614.0	-4.111×10^{-3}	2.958×10^{-5}	-5.302×10^{-8}
4131.7	-3.730×10^{-3}	2.683×10^{-5}	-4.807×10^{-8}

TABLE XV. Coefficients of the Equation $(P-P_o)^{-1} \times \ln(R) = B_1 + B_2T + B_3T^2$ for Sea Water of Salinity 34.099°/oo

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THIS PROGRAM TAKES THE RAW EXPERIMENTAL DATA OF TEMPERATURE,
    PRESSURE, AND PESISTANCE AND COMPUTES THE SPECIFIC CON-
    DUCTANCE OF SEA WATER.  IT WILL ALSO COMPUTE THE TEMPER-
    ATURE COEFFICIENTS FOR EACH WATER SAMPLE AT EACH
    PRESSURE AND THE PRESSURE COEFFICIENTS AT EACH
    TEMPERATURE.

THE VARIABLES USED IN THIS PROGRAM ARE:

  SAL=SALINITY OF WATER SAMPLES.
  P=PRESSURE (PSI).
  PD=PRESSURE (DECIBARS).
  RTN=RESISTANCE OF SAMPLE 'N'; WHERE (=1,2,3,...,K.
  CONDN=SPECIFIC CONDUCTANCE OF SAMPLE 'N';
     WHERE N=1,2,3,...,K.

THE OTHER VARIABLES THAT ARE DIMENSIONED ARE USED FOR
    TEMPORARY STORAGE OR FOR TITLING PURPOSES.

CONSTANTS USED IN THIS PROGRAM ARE:

  K=NUMBER OF WATER SAMPLES.
  L=NUMBER OF PRESSURES MEASURED (PSI).
  M=NUMBER OF TEMPERATURES MEASURED (DEG. C).
  FACT=FACTOR TO CONVERT PSI TO DECIBARS.
  DH=DIAMETER OF HYDRAULIC PISTON (INCHES).
  DV=DIAMETER OF PRESSURE VESSEL PISTON (INCHES).
  CELL1=CELL CONSTANT FOR CELL ONE (MHO/CM).
  CELL2=CELL CONSTANT FOR CELL TWO (MHO/CM).  NOT REQUIRED
      IF ONLY ONE CELL USED.

       REAL*8 ITITLE(12,15),TITLE(10,15),DCON1(10),DCON2(10),
      *DCON3(10),YAA(10,YAB(10),YAC(10),B(10),SB(10),DPD(10),
      *ITATLE(12),TATLE(12),W(10),DELY(10),

       REAL*8 ITOTLE(12,10),TOTLE(10,10),CON1(15),CON2(15),
      *CON3(15),YTA(15),YTB(15),YTC(15),C(15),SC(15),EPSY(15)
      *,DT(15),WT(15)

       REAL*8 DTRH1(15),DTRH2(15),DTRH3(15),DXRH1(10),
      *DXRH2(10),DXRH3(10),E(15),DTRY(15),XTA(15),SE(15),
      *XTB(15,XTC(15),D(10),SD(10),DERY(10),XAA(10),XAB(10),
      *XAC(10)

       REAL*8 ITETLE(12),TETLE(10)

       REAL*8 TTTLE(10)/10*' '/

       REAL LABEL/4H    /

       DIMENSION SAL(5),P(10),PD(10),T(15),RT1(15,10),
      *RT2(15,10),RT3(15,10),COND1(15,10),COND2(15,10),
      *COND3(15,10)

       DIMENSION DUM1(10),DUM2(10),DUM3(10),TEM1(10),TEM2(10)
      *,TEM3(10)
       DIMENSION DMY1(15),DMY2(15),DMY3(15),TMP1(15),TMP2(15)
      *,TMP3(15)

       DIMENSION TRH1(15),TRH2(15),TRH3(15),XRH1(10),XRH2(10)
      *XRH3(10)

       DATA FACT/0.68947/,DH/1.875/,DV/1.530/,CELL1/0.63878/
      *,CELL2/0.75123/

READ THE RAW DATA IN.

       READ(5,1) K,L,M
     1 FORMAT(3I3)
```

```
      READ(5,2) (SAL(I),I=1,K)
    2 FORMAT(3F6.3)
      READ(5,3) (P(I),I=1,L)
    3 FORMAT(9F5.0)
      READ(5,4) (T(I),I=1,M)
    4 FORMAT(10F5.2)
      READ(5,6) ((RT1(I,J),J=1,L),I=1,M)
      READ(5,6) ((RT2(I,J),J=1,L),I=1,M)
      READ(5,6) ((RT3(I,J),J=1,L),I=1,M)
    6 FORMAT(9F6.3)

READ THE INFORMATION FOR TITLING.

      READ(5,7) ((ITITLE(I,J),I=1,12),J=1,M)
      READ(5,7)  ((TITLE(I,J),I=1,10),J=1,M)
    7 FORMAT(6A8)
      READ(5,8) ((ITOTLE(I,J),I=1,12),J=1,L)
      READ(5,8) ((TOTLE(I,J),I=1,10),J=1,L)
    8 FORMAT(6A8)

ECHO CHECK THE DATA.

      DO10 I=1,K
      WRITE(6,1005) SAL(I)
 1005 FORMAT('1',5X,F6.3,/)
      DO11 J=1,M
      WRITE(6,1015) T(J)
 1015 FORMAT(5X,F5.2)
      IF(I.EQ.2) GOTO 20
      IF(I.EQ.3) GOTO 30
      DO12 N=1,L
   12 WRITE(6,1025) P(N),RT1(J,N)
      GOTO 40
   20 DO13 NN=1,L
   13 WRITE(6,1025) P(NN),RT2(J,NN)
      GOTO 40
  30  DO14 NM=1,L
   14 WRITE(6,1025) P(NM),RT3(J,NM)
 1025 FORMAT(5X,F5.0,5X,F6.3,/)
   40 CONTINUE
   11 CONTINUE
   10 CONTINUE

CONVERT PSI TO DECIBARS.

      DO100 I=1,L
  100 PD(I)=P(I)*((DH/DV)**2)*FACT

CONVERT RESISTANCE TO OBSERVED SPECIFIC CONDUCTANCE.

      DO200 I=1,M
      DO210 J=1,L
      COND1(I,J)=1.0/RT1(I,J)
      COND2(I,J)=1.0/RT2(I,J)
      COND3(I,J)=1.0/RT3(I,J)

REMOVE THE CARDS FROM HERE THROUGH GOTO 210 STATMENT IF
    ONLY ONE CELL HAS BEEN USED.

      IF(I.GE.11) GOTO 250
      COND1(I,J)=COND1(I,J)*CELL2
      COND2(I,J)=COND2(I,J)*CELL2
      COND3(I,J)=COND3(I,J)*CELL2
      GOTO 210
  250 COND1(I,J)=COND1(I,J)*CELL1
      COND2(I,J)=COND2(I,J)*CELL1
      COND3(I,J)=COND3(I,J)*CELL1
  210 CONTINUE
  200 CONTINUE
```

```
PRINT THE RESULTS.

      DO300 I=1,K
      WRITE(6,2000) SAL(I)
 2000 FORMAT('1',32X,' SALINITY=',6X,F6.3,/)
      DO310 J=1,M
      WRITE(6,2100) T(J)
 2100 FORMAT(32X,' TEMPERATURE=',3X,F5.2,/)
      WRITE(6,2200)
 2200 FORMAT(25X,' PRESSURE',2X,' SPECIFIC CONDUCTANCE',//)
      IF(I.EQ.2) GOTO 350
       IF(I.EQ.3) GOTO 360
      DO320 N=1,L
  320 WRITE(6,2300) PD(N),COND1(J,N)
      GOTO 370
  350 DO330 NN=1,L
  330 WRITE(6,2300) PD(NN),COND2(J,NN)
      GOTO 370
  360 DO340 NM=1,L
  340 WRITE(6,2300) PD(NM),COND3(J,NM)
 2300 FORMAT(26X,F6.1,9X,F7.6,/)
  370 CONTINUE
  310 CONTINUE
  300 CONTINUE

CONVERT TO DOUBLE PRECISION AND TO ONE DIMENSION ARRAYS FOR
    SPECIFIC CONDUCTANCE AND COMPUTE THE LEAST SQUARES POLY-
    NOMIAL FIT TO THE DATA.  PLOT THE RESULTS OF THE HIGHEST
    DEGREE POLYNOMIAL AND THE DATA.  (PRESSURE COEFFICIENTS)

      DO400 I=1,M
      DO410 J=1,L
      DCON1(J)=COND1(I,J)
      DCON2(J)=COND2(I,J)
      DCON3(J)=COND3(I,J)
      DPD(J)=PD(J)
      DUM1(J)=COND1(I,J)
      DUM2(J)=COND2(I,J)
      DUM3(J)=COND3(I,J)
      W(J)=1.0D0
  410 CONTINUE
      DO415 N=1,10
      TATLE(N)=TITLE(N,I)
  415 CONTINUE

THIS SUBROUTINE IN NPGS SOURCE LIBRARY.

      CALL LSQPL2(L,3,DPD,DCON1,W,YAA,DELY,B,SB,TATLE)
      CALL LSQPL2(L,3,DPD,DCON2,W,YAB,DELY,B,SB,TATLE)
      CALL LSQPL2(L,3,DPD,DCON3,W,YAC,DELY,B,SB,TATLE)
      DO420 NN=1,12
      ITATLE(NN)=ITITLE(NN,I)
  420 CONTINUE

THE 0.025 IS A SCALING FACTOR FOR THE DATA OF THIS STUDY.

      DO425 NM=1,L
      TEM1(NM)=YAA(NM)-0.025D0
      TEM2(NM)=YAB(NM)-0.025D0
      TEM3(NM)=YAC(NM)-0.025D0
      DUM1(NM)=DUM1(NM)-0.025
      DUM2(NM)=DUM2(NM)-0.025
      DUM3(NM)=DUM3(NM)-0.025
  425 CONTINUE

THIS SUBROUTINE IN NPGS SOURCE LIBRARY.

       CALL DRAW(L,PD,DUM1,1,1,LABEL,ITATLE,700.0,0.003,0,0,0
     *,0,6,8,0,LAST)
       CALL DRAW(L,PD,TEM1,3,0,LABEL,ITATLE,700.0,0.003,0,0,0
     *,0,6,8,0,LAST)
```

```
      CALL DRAW(L,PD,DUM2,1,2,LABEL,ITATLE,700.0,0.003,0,0,0
     *,0,6,8,0,LAST)
      CALL DRAW(L,PD,TEM2,3,0,LABEL,ITATLE,700.0,0.003,0,0,0
     *,0,6,8,0,LAST)
      CALL DRAW(L,PD,DUM3,1,3,LABEL,ITATLE,700.0,0.003,0,0,0
     *,0,6,8,0,LAST)
      CALL DRAW(L,PD,TEM3,3,0,LABEL,ITATLE,700.0,0.003,0,0,0
     *,0,6,8,0,LAST)
  400 CONTINUE

CONVERT TO DOUBLE PRECISION AND TO ONE DIMENSION ARRAY FOR
    SPECIFIC CONDUCTANCE AND COMPUTE THE LEAST SQUARES POLY-
    NOMIAL FIT TO THE DATA.  PLOT THE RESULTS OF THE HIGHEST
    DEGREE POLYNOMIAL AND THE DATA.  (TEMPERATURE COEFF.)

      DO401 J=1,L
      DO411 I=1,M
      CON1(I)=COND1(I,J)
      CON2(I)=COND2(I,J)
      CON3(I)=COND3(I,J)
      DT(I)=T(I)
      DMY1(I)=COND1(I,J)-0.025
      DMY2(I)=COND2(I,J)-0.025
      DMY3(I)=COND3(I,J)-0.025
      WT(I)=1.0D0
  411 CONTINUE
      DO412 N=1,10
      TETLE(N)=TOTLE(N,J)
  412 CONTINUE
      KM=3

   KM=THE DEGREE OF FIT.

      CALL LSQPL2(M,KM,DT,CON1,WT,YTA,EPSY,C,SC,TETLE)
      CALL LSQPL2(M,KM,DT,CON2,WT,YTB,EPSY,C,SC,TETLE)
      CALL LSQPL2(M,KM,DT,CON3,WT,YTC,EPSY,C,SC,TETLE)
      DO413 NN=1,12
      ITETLE(NN)=ITOTLE(NN,J)
  413 CONTINUE
      DO414 NM=1,M
      TMP1(NM)=YTA(NM)-0.025D0
      TMP2(NM)=YTB(NM)-0.025D0
      TMP3(NM)=YTC(NM)-0.025D0
  414 CONTINUE
      CALL DRAW(M,T,DMY1,1,1,LABEL,ITETLE,4.0,0.003,0,0,0,0,
     *6,8,0,LAST)
      CALL DRAW(M,T,TMP1,3,0,LABEL,ITETLE,4.0,0.003,0,0,0,0,
     *6,8,0,LAST)
      CALL DRAW(M,T,DMY2,1,2,LABEL,ITETLE,4.0,0.003,0,0,0,0,
     *6,8,0,LAST)
      CALL DRAW(M,T,TMP2,3,0,LABEL,ITETLE,4.0,0.003,0,0,0,0,
     *6,8,0,LAST)
      CALL DRAW(M,T,DMY3,1,3,LABEL,ITETLE,4.0,0.003,0,0,0,0,
     *6,8,0,LAST)
      CALL DRAW(M,T,TMP3,3,0,LABEL,ITETLE,4.0,0.003,0,0,0,0,
     *6,8,0,LAST)
  401 CONTINUE

COMPUTE THE LEAST SQUARES FIT TO THE OBSERVED CONDUCTIVITY
    RATIO.  THE FORM OF THE EQUATION DESIRED IS:
     LN(R)/(P-P1)=A(1)+A(2)*T+A(3)*T**2

      DO167 I=1,M
      T(I)=T(I)+273.16
      DT(I)=T(I)
  167 CONTINUE
      PD(1)=10.13
      DO137 J=1,L
      PD(J)=PD(J)-PD(1)
      DPD(J)=PD(J)
  137 CONTINUE
```

```
      WT(1)=1.0D0
      DO169 J=2,L
      DO168 I=1,M
      TRH1(I)=ALOG(RH1(I,J))/PD(J)
      TRH2(I)=ALOG(RH2(I,J))/PD(J)
      TRH3(I)=ALOG(RH3(I,J))/PD(J)
      WT(I)=1.0D0
      DTRH1(I)=TRH1(I)
      DTRH2(I)=TRH2(I)
      DTRH3(I)=TRH3(I)
  168 CONTINUE
      DTRH1(1)=0.0D0
      DTRH2(1)=0.0D0
      DTRH3(1)=0.0D0
      CALL LSQPL2(M,3,DT,DTRH1,WT,XTA,DTRY,E,SE,TTTLE)
      CALL LSQPL2(M,3,DT,DTRH2,WT,XTB,DTRY,E,SE,TTTLE)
      CALL LSQPL2(M,3,DT,DTRH3,WT,XTC,DTRY,E,SE,TTTLE)
  169 CONTINUE

COMPUTE THE LEAST SQUARES FIT TO THE OBSERVED CONDUCTIVITY
    RATIO.  THE FORM OF THE EQUATION DESIRED IS:
     LN(R)/T=A(1)+A(2)*(P-P1)+A(3)*(P-P1)**2

      DO199 I=1,M
      DO198 J=1,L
      XRH1(J)=ALOG(RH1(I,J))/T(I)
      XRH2(J)=ALOG(RH2(I,J))/T(I)
      XRH3(J)=ALOG(RH3(I,J))/T(I)
      DXRH1(J)=XRH1(J)
      DXRH2(J)=XRH2(J)
      DXRH3(J)=XRH3(J)
      W(J)=1.0D0
  198 CONTINUE
      CALL LSQPL2(L,3,DPD,DXRH1,W,XAA,DERY,D,SD,TTTLE)
      CALL LSQPL2(L,3,DPD,DXRH2,W,XAB,DERY,D,SD,TTTLE)
      CALL LSQPL2(L,3,DPD,DXRH3,W,XAC,DERY,D,SD,TTTLE)
  199 CONTINUE
      STOP
      END
```

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13. ABSTRACT

The specific conductance of three sea water samples (33.634°/oo, 34.099°/oo and 35.001°/oo) was measured at twelve temperatures from 0°C to 21.00°C and at nine pressures from atmospheric to 4,141.8 decibars above atmospheric. Polynomials for specific conductance as a function of temperature and as a function of pressure are computed from the data, but the temperature-pressure effect is obscure.

Two empirical equations that relate conductivity ratio to temperature and pressure are also developed. These equations better describe the temperature-pressure effect on conductivity at the pressures studied which correspond to the upper 4,000 meters of the ocean.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Conductivity Ratio						
Specific Conductance						
Salinity						
Sea Water						
Temperature						
Pressure						

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Hassler
The temperature-
pressure dependence of
ionic conductivity in
sea water at tempera-
ture in the oceanic.